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Automatic fault tree construction with RIKKE - a compendium of examples. Volume 2. Control and safety loops

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AUTOMATIC FAULT TREE CONSTRUCTION WITH RIKKE - A COMPENDIUM OF EXAMPLES. VOLUME 2. CONTROL AND SAFETY LOOPS.

J.R. Taylor

Abstract. This second volume describes the construction of fault trees for systems with loops, including control and safety loops. It also gives a short summary of the event coding scheme used in the FTLIB component model library.

INIS descriptors. CONTROL EQUIPMENT: ELECTRICAL EQUIPMENT; FAULT TREE ANALYSIS; INDUSTRIAL PLANTS; POWER PLANTS; RISK ANALYSIS.

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NOTE

The models used in volume I contained a feature which allowed BLOCKED pipes to give HIFLO. This occurred in fault tree 8 and 25. Although this gives a conservative estimate of risk, the model appears illogical. This effect has been eliminated in the models used in volume 2.

INTRODUCTION AND EXAMPLES

In this volume, examples of RIKKE fault tree construction including loops are given. The principles involved were described in volume I and in (1).

Example 1

The first example, TEST 12, shows a tank level regulator with high and low level trips. The first fault tree is for a DISTHI, disturbance, that is, slightly high level, in the tank. The top event is caused by flow disturbances in C5, or C4, or C15, together with regulator failure to regulate. by drift in the regulator loop itself, or by a blockage or disturbed supply.

The second fault tree shows the causes of a large level disturbance. It illustrates that both the regulating valve and the shutdown valve can serve to correct the high level disturbance.

The fault tree for the HI disturbance is so big that it cannot be plotted completely on a 10,000 x 10,000 point plotting plane. For this reason, minimal cut sets up to fourth order for this fault tree have been evaluated and listed. The cut sets were evaluated using FAUNET and the FAUNET interface programs included in RIKKE III. In all there are 114 cut sets of fourth order, 120 of fifth order and six cut sets of sixth order.

During evaluation of the HI fault tree an interesting effect was observed. The shut off valve, if it closes, will prevent the regulator valve from regulating. RIKKE therefore assumed, conservatively, that such a shut down will always occur. This of course, led to the non conservative result, that the shutoff valve would always close. In producing the tree, the effect was eliminated during interactive tree building. The effect should be eliminated automatically in RIKKE III. The effect is an example of some of the practical pitfalls in automatic fault tree construction.

Example 2

TEST 13 is a redundant gas regulator circuit with cross coupling to two gas flow sensors. The sensors are represented by the "load" components C13 and C15.

The main interest of this example is that it is a cross coupled redundant network, with positive feed forward effects in the fault tree.

The network is near the limit of what can be analysed automatically "in one go" using RIKKE 2.5 and FTLIB. Larger systems require either interactive steering of the construction, or modular construction of the fault tree (that is, construction "a piece at a time").

Example 3

TEST 14 is Lapp and Powers classic example of automatic fault tree construction (2). The traditional failure mode "controller reversed" has been omitted, since it is nonsensical for a running system (see 3). "Fire" as a cause of high temperature has been omitted since this is treated separately in standard RIKKE procedures. The construction, from start of drawing of the flow sheet, to completion of fault tree plots, took under one hour, of which about 15 minutes was drawing time.

Standard FTLIB component models were used throughout, the only difficulties arising being to get inverters (C14, C17) placed so that loops were correctly connected.

Example 4

TEST 24 is a very simple small safety loop, its only merit being to demonstrate a model of a normally closed valve.

Example 5

TEST 23 is a relatively large multi feed forward loop system. The model was made as part of the preparations for a large benchmark exercise.

The fault tree was made in one pass, that is, without modularization, by the use of interactive steering. The analyst stopped fault tree construction where redundant loop traverses were made. The stopping points can be seen as bucket shaped boxes on the fault tree. These could be eliminated from the fault tree without underestimating risk.

Example 6

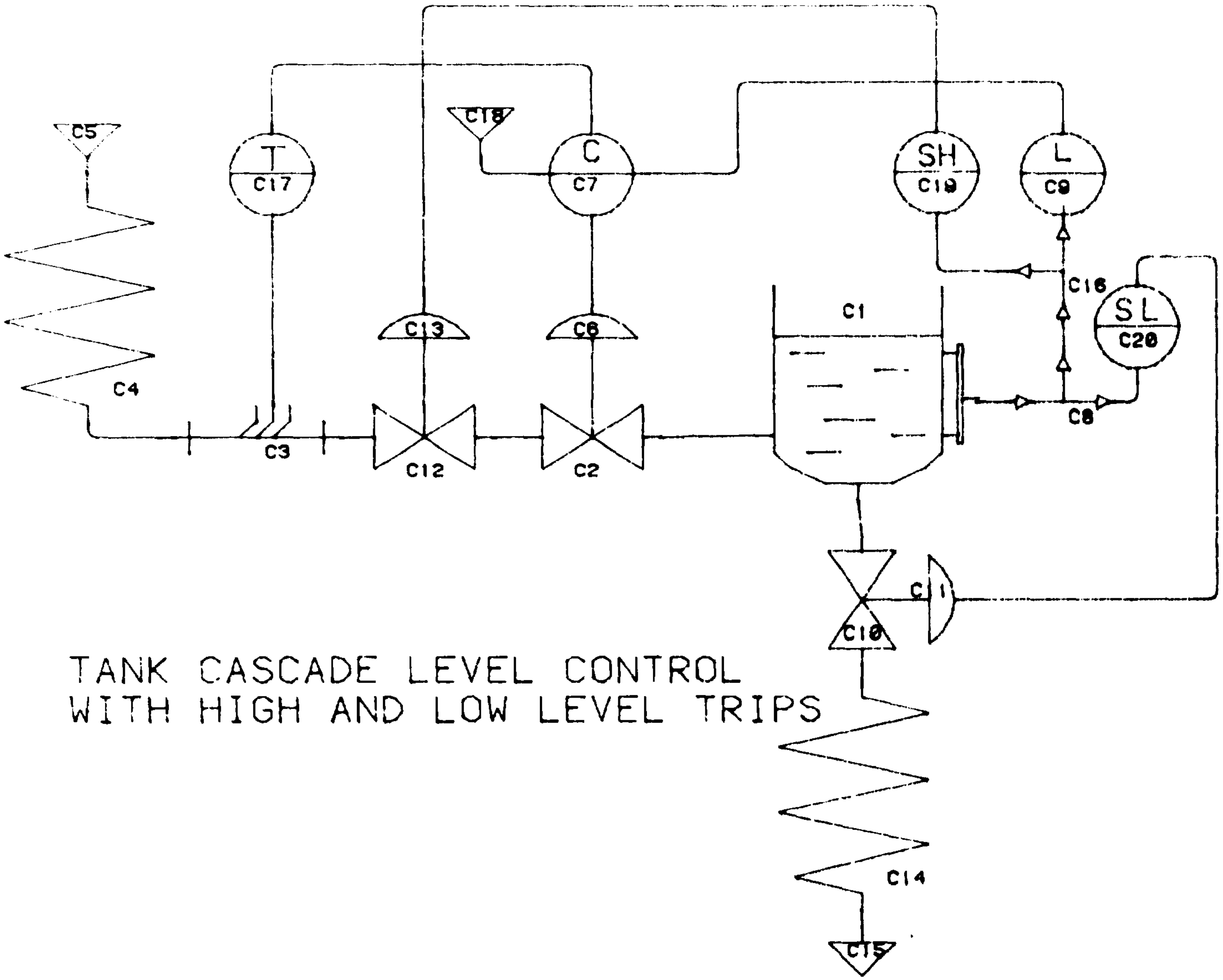
TEST 24 is a ratio controller for concentration. It is included to show that RIKKE can be used for quite a wide range of disturbance types.

REFERENCES

(1) J.R. Taylor, An Algorithm for Fault Tree Construction. To be published in IEEE Trans. on Reliability.

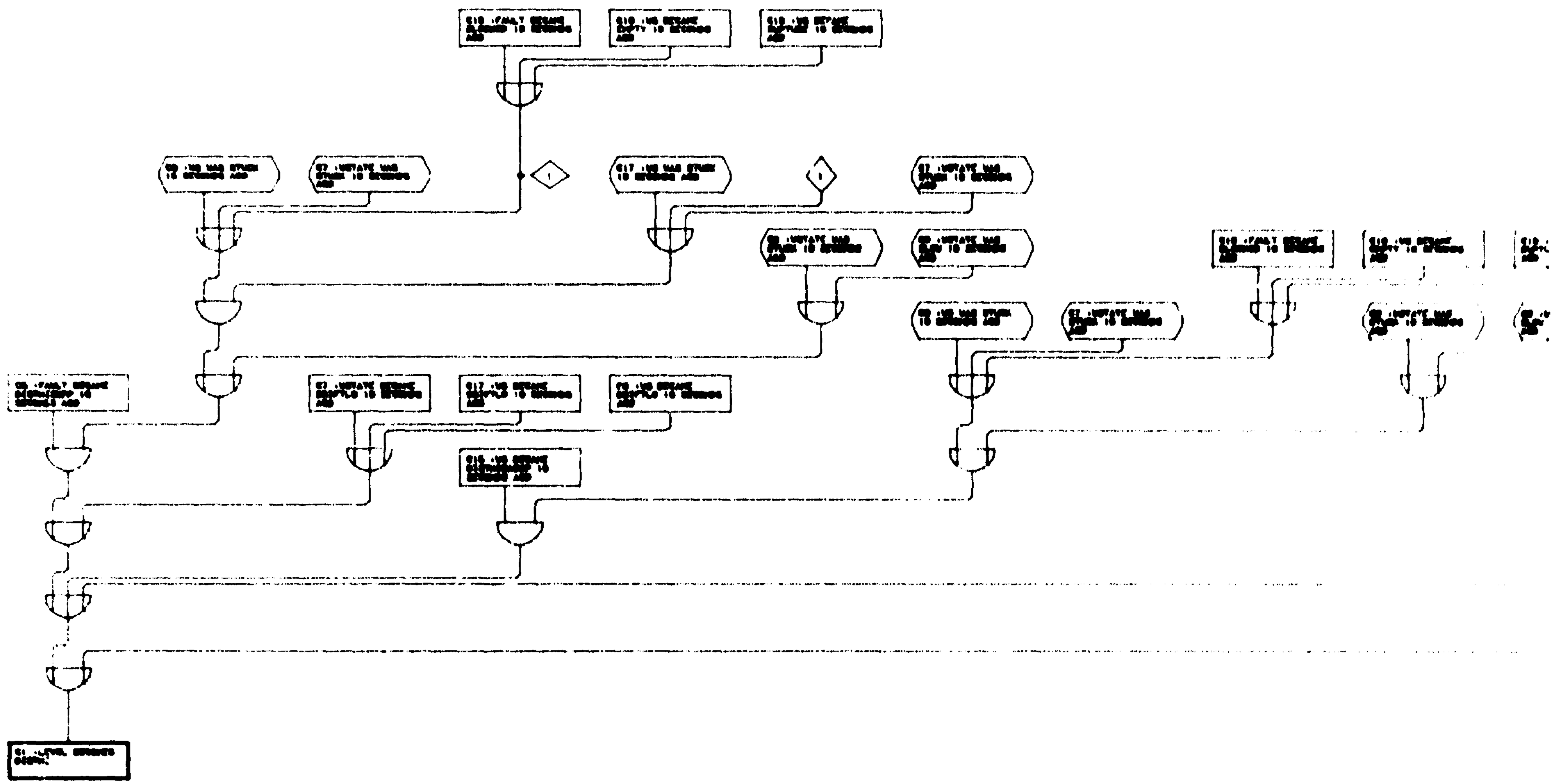
(2) S.A. Lapp and G.J. Powers, Computer Aided Synthesis of Fault Trees. IEEE Trans. Reliability, Vol. R26, pp. 2-13, 1977.

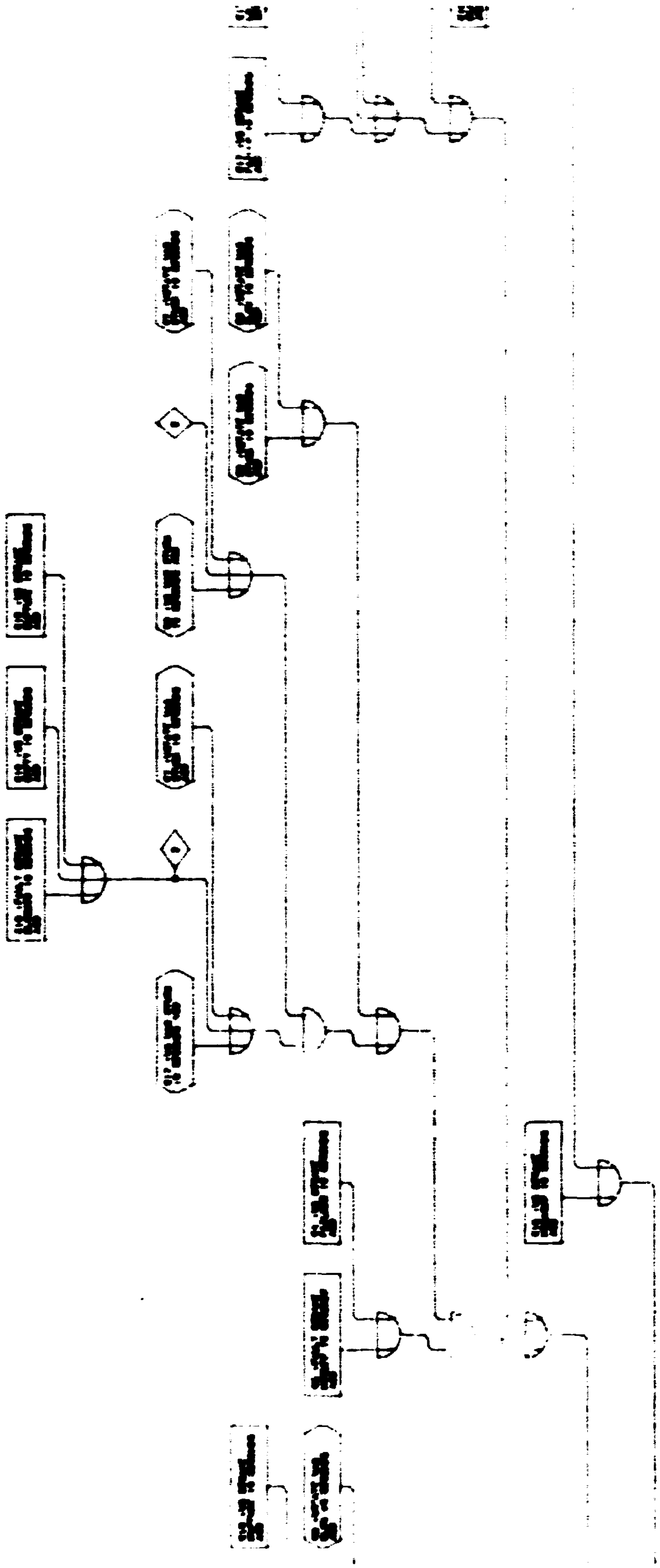
(3) J.R. Taylor, Letter in IEEE Trans. Reliability, Vol. R28, pp. 114, No. 2, June 1979.

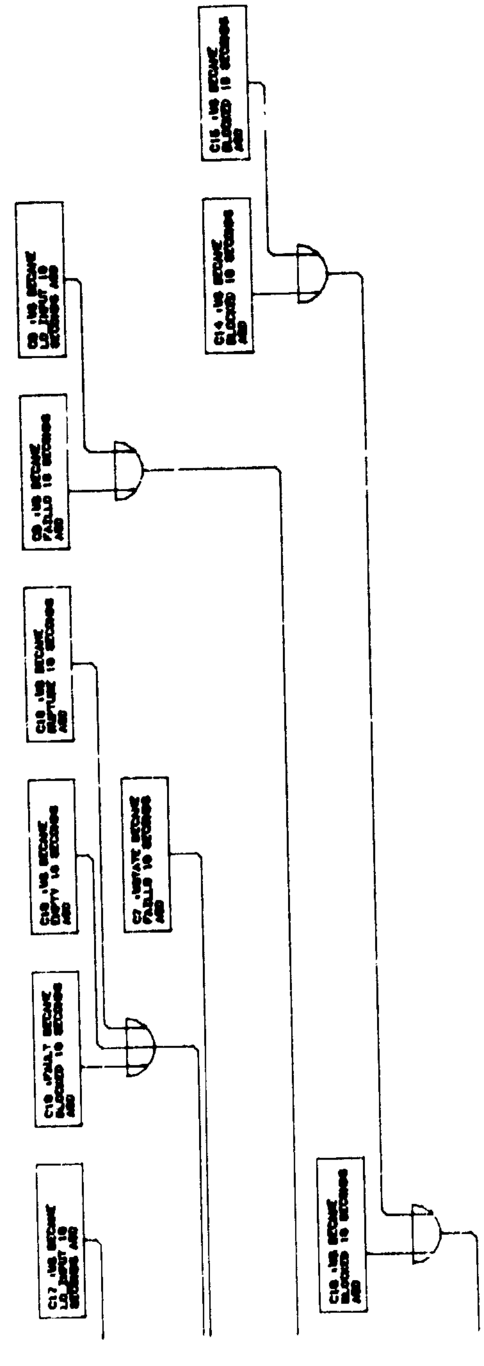


TANK CASCADE LEVEL CONTROL
WITH HIGH AND LOW LEVEL TRIPS

x TEST 12 4.5 MIN.







Minimal cut sets found in model: X FROM TEST12

Top event in component C1 :LEVEL BECOMES HI

Cut sets of 4th order:

1) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO

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2) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO

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3) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO

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4) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO

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5) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO

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6) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO

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7) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO

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8) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO

---

9) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO

and in C13 :WSTATE WAS SLOW 10 SECONDS AGO

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10) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO

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11) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO

----

12) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO

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13) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO

----

14) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO

----

15) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO

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16) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C1 :OUT WAS NOT DRAINED 10 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO

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17) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C1 :OUT WAS NOT DRAINED 10 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO

----

18) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :WS BECAME RUPTURE 10 SECONDS AGO
and in C1 :OUT WAS NOT DRAINED 10 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO

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   19) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C4 :IN BECAME SCUM 11 SECONDS AGO
         and in C19 :WS WAS STUCK 10 SECONDS AGO


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   20) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C4 :IN BECAME SCUM 11 SECONDS AGO
         and in C13 :WSTATE WAS STUCK 10 SECONDS AGO


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   21) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C4 :IN BECAME SCUM 11 SECONDS AGO
         and in C13 :WSTATE WAS SLOW 10 SECONDS AGO


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   22) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
         and in C19 :WS WAS STUCK 10 SECONDS AGO


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   23) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
         and in C13 :WSTATE WAS STUCK 10 SECONDS AGO


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   24) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
         and in C13 :WCTATE WAS SLOW 10 SECONDS AGO


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   25) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
         and in C19 :WS WAS STUCK 10 SECONDS AGO


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   26) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
         and in C13 :WSTATE WAS STUCK 10 SECONDS AGO


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   27) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
         and in C13 :WSTATE WAS SLOW 10 SECONDS AGO


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   28) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
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         and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
         and in C19 :WS WAS STUCK 10 SECONDS AGO


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   29) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
         and in C13 :WSTATE WAS STUCK 10 SECONDS AGO


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   30) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
         and in C13 :WSTATE WAS SLOW 10 SECONDS AGO


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   31) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
         and in C19 :WS WAS STUCK 10 SECONDS AGO


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   32) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
         and in C13 :WSTATE WAS STUCK 10 SECONDS AGO


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   33) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
         and in C13 :WSTATE WAS SLOW 10 SECONDS AGO


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   34) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C1 :OUT WAS NOT DRAINED 10 SECONDS AGO
         and in C19 :WS WAS STUCK 10 SECONDS AGO


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   35) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C1 :OUT WAS NOT DRAINED 10 SECONDS AGO
         and in C13 :WSTATE WAS STUCK 10 SECONDS AGO


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   36) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :WS BECAME EMPTY 10 SECONDS AGO
         and in C1 :OUT WAS NOT DRAINED 10 SECONDS AGO
         and in C13 :WSTATE WAS SLOW 10 SECONDS AGO


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   37) Fault in C4 : [illegible] DID NOT BECOME SHUTOFF 10 SECONDS AGO
         and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
         and in C4 :IN BECAME SCUM 11 SECONDS AGO
         and in C19 :WS WAS STUCK 10 SECONDS AGO
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38) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO

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39) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO

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40) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO

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41) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO

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42) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO

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43) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO

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44) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO

---

45) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO

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46) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO

---

47) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO

and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO

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48) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO

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49) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO

----

50) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO

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51) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO

----

52) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C1 :OUT WAS NOT DRAINED 10 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO

----

53) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C1 :OUT WAS NOT DRAINED 10 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO

----

54) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C18 :FAULT BECAME BLOCKED 10 SECONDS AGO
and in C1 :OUT WAS NOT DRAINED 10 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO

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55) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C9 :WS WAS STUCK 10 SECONDS AGO

----

56) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C7 :WSTATE WAS STUCK 10 SECONDS AGO

----

57) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS STUCK 10 SECONDS AGO

----

58) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS SLOW 10 SECONDS AGO

----

59) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C9 :WS WAS STUCK 10 SECONDS AGO

----

60) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C7 :WSTATE WAS STUCK 10 SECONDS AGO

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61) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS STUCK 10 SECONDS AGO

----

62) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS SLOW 10 SECONDS AGO

----

63) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C9 :WS WAS STUCK 10 SECONDS AGO

----

64) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C7 :WSTATE WAS STUCK 10 SECONDS AGO

----

65) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C6 :WSTATE WAS STUCK 10 SECONDS AGO

----

66) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C4 :IN BECAME SCUM 11 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C6 :WSTATE WAS SLOW 10 SECONDS AGO

----

67) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C9 :WS WAS STUCK 10 SECONDS AGO

----

68) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C7 :WSTATE WAS STUCK 10 SECONDS AGO

----

69) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS STUCK 10 SECONDS AGO

----

70) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS SLOW 10 SECONDS AGO

----

71) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C9 :WS WAS STUCK 10 SECONDS AGO

----

72) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C7 :WSTATE WAS STUCK 10 SECONDS AGO

----

73) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS STUCK 10 SECONDS AGO

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74) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS SLOW 10 SECONDS AGO

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75) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO

and in C9 :WS WAS STUCK 10 SECONDS AGO

----

76) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C7 :WSTATE WAS STUCK 10 SECONDS AGO

----

77) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C6 :WSTATE WAS STUCK 10 SECONDS AGO

----

78) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C7 :WSTATE BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C6 :WSTATE WAS SLOW 10 SECONDS AGO

----

79) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C9 :WS WAS STUCK 10 SECONDS AGO

----

80) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C7 :WSTATE WAS STUCK 10 SECONDS AGO

----

81) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS STUCK 10 SECONDS AGO

----

82) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS SLOW 10 SECONDS AGO

----

83) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C9 :WS WAS STUCK 10 SECONDS AGO

----

84) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C7 :WSTATE WAS STUCK 10 SECONDS AGO

---

85) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS STUCK 10 SECONDS AGO

---

86) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS SLOW 10 SECONDS AGO

---

87) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C9 :WS WAS STUCK 10 SECONDS AGO

---

88) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C7 :WSTATE WAS STUCK 10 SECONDS AGO

---

89) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C6 :WSTATE WAS STUCK 10 SECONDS AGO

---

90) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C9 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C6 :WSTATE WAS SLOW 10 SECONDS AGO

---

91) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C9 :WS WAS STUCK 10 SECONDS AGO

---

92) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C7 :WSTATE WAS STUCK 10 SECONDS AGO

---

93) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS STUCK 10 SECONDS AGO

---

94) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO

and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS SLOW 10 SECONDS AGO

----

95) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C9 :WS WAS STUCK 10 SECONDS AGO

----

96) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C7 :WSTATE WAS STUCK 10 SECONDS AGO

----

97) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS STUCK 10 SECONDS AGO

----

98) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS SLOW 10 SECONDS AGO

----

99) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C9 :WS WAS STUCK 10 SECONDS AGO

----

100) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C7 :WSTATE WAS STUCK 10 SECONDS AGO

----

101) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C6 :WSTATE WAS STUCK 10 SECONDS AGO

----

102) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C17 :WS BECAME DRIFTLO 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C6 :WSTATE WAS SLOW 10 SECONDS AGO

----

103) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C9 :WS WAS STUCK 10 SECONDS AGO

----

104) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C7 :WSTATE WAS STUCK 10 SECONDS AGO

----

105) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS STUCK 10 SECONDS AGO

----

106) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C19 :WS WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS SLOW 10 SECONDS AGO

----

107) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C9 :WS WAS STUCK 10 SECONDS AGO

----

108) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C7 :WSTATE WAS STUCK 10 SECONDS AGO

----

109) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS STUCK 10 SECONDS AGO

----

110) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C13 :WSTATE WAS STUCK 10 SECONDS AGO
and in C6 :WSTATE WAS SLOW 10 SECONDS AGO

----

111) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C9 :WS WAS STUCK 10 SECONDS AGO

----

112) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C13 :WSTATE WAS SLOW 10 SECONDS AGO
and in C7 :WSTATE WAS STUCK 10 SECONDS AGO

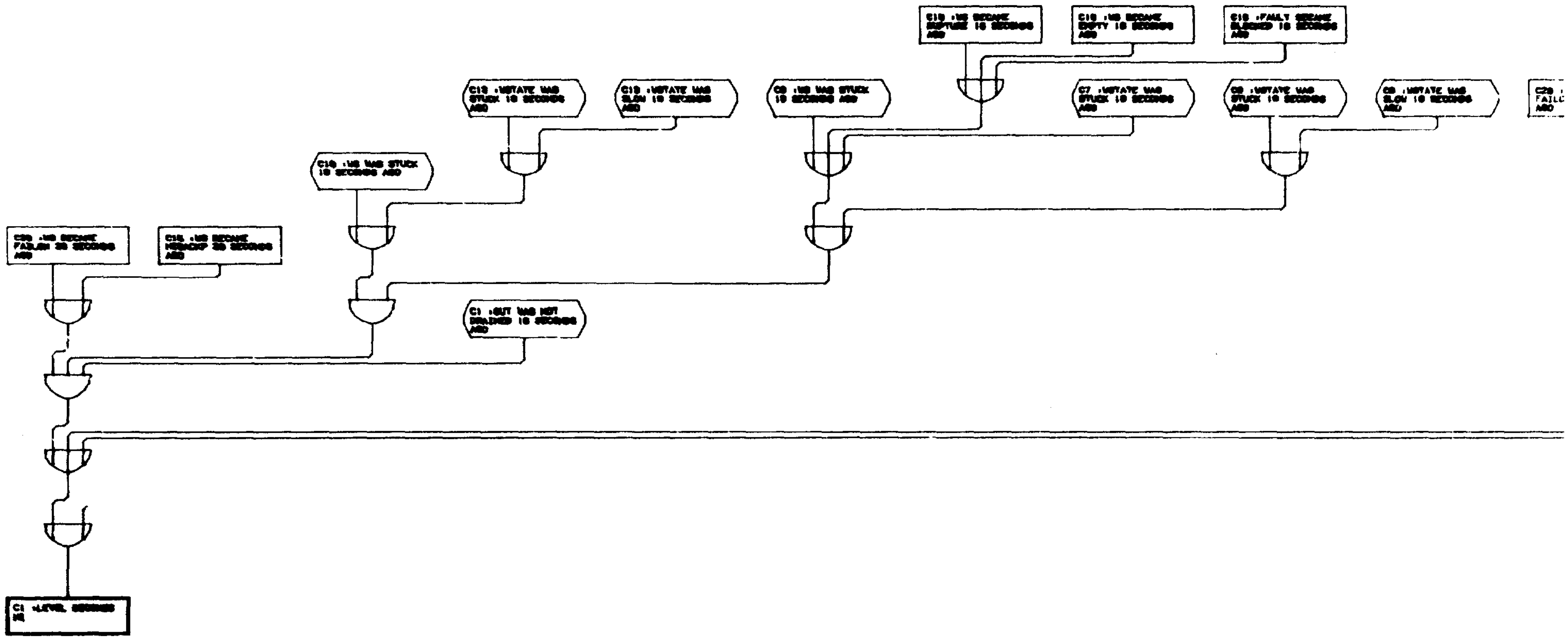
----

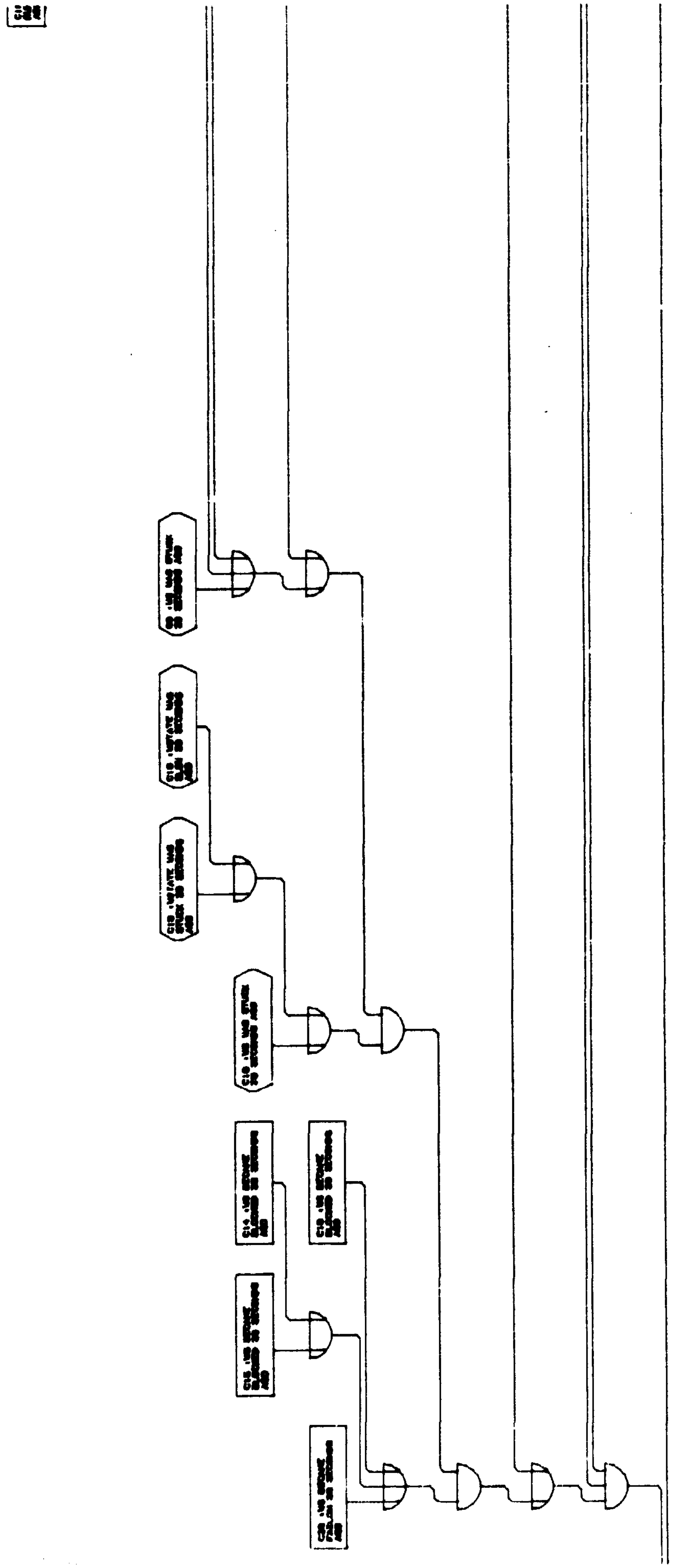
113) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO

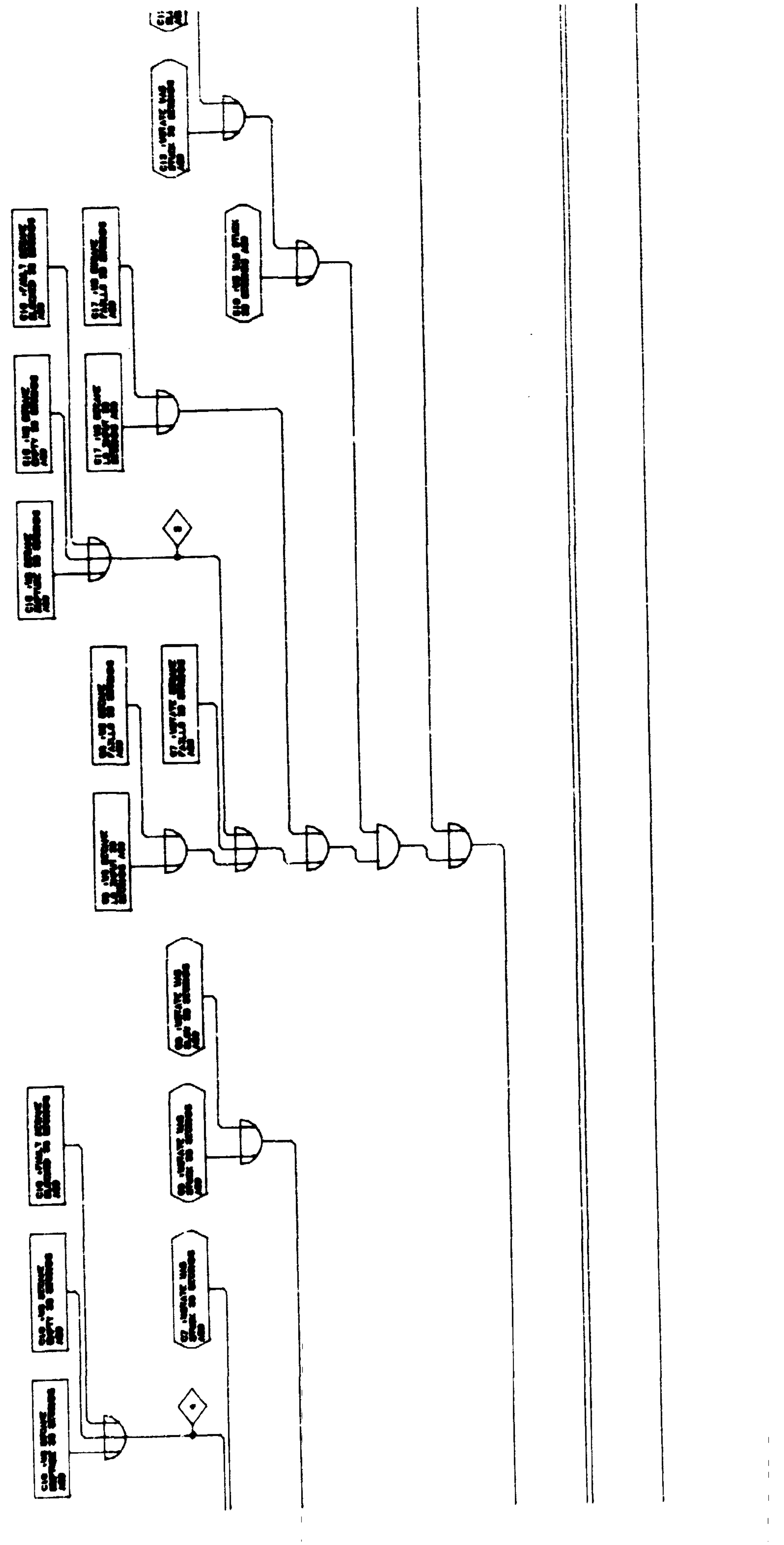
and in C5 :FAULT BECAME DISTHISU[illegible] SECONDS AGO
and in C13 :USTATE WAS SLOW [illegible] SECONDS AGO
and in C6 :USTATE WAS STUCK 10 SECONDS AGO

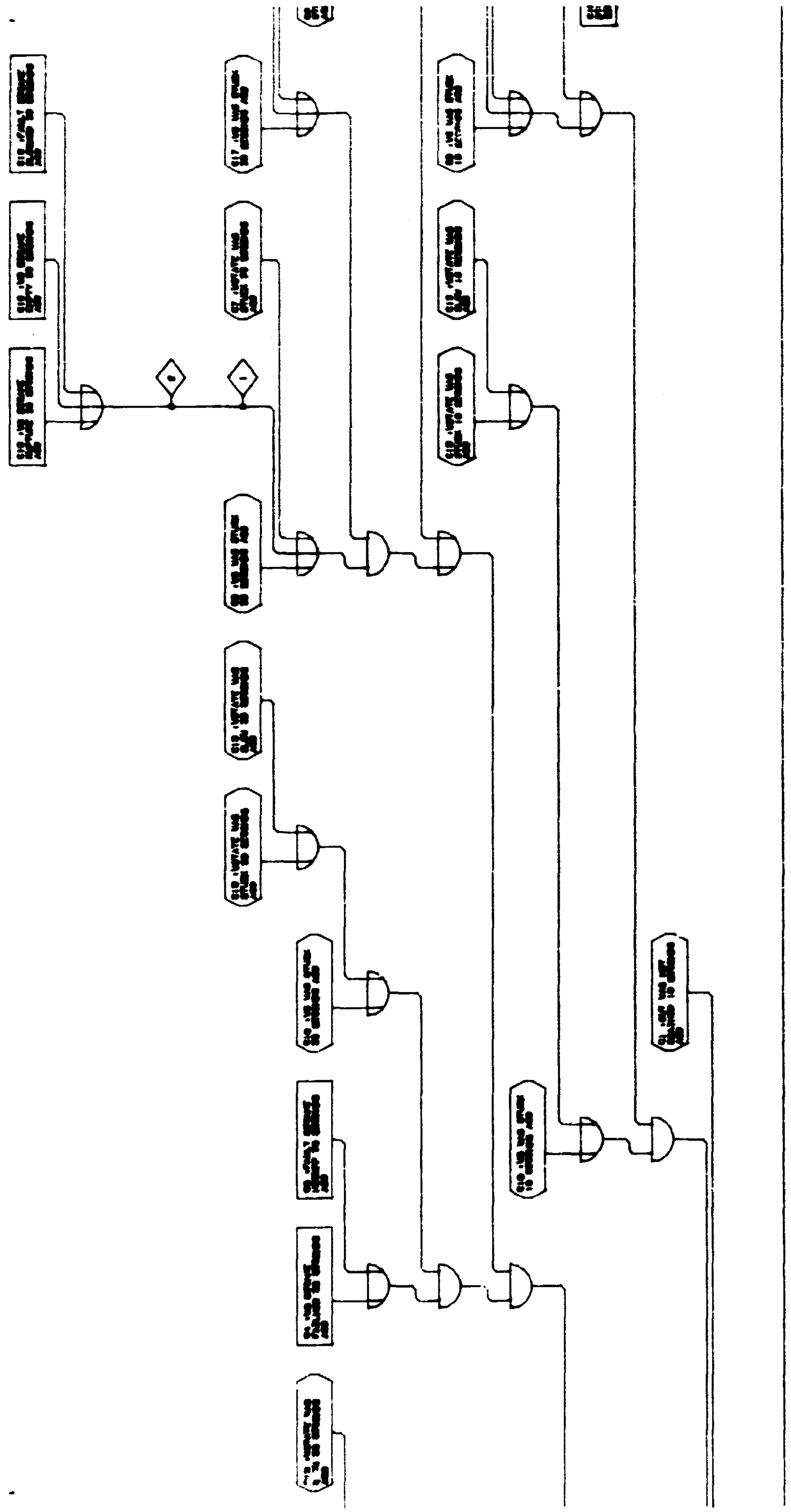
----

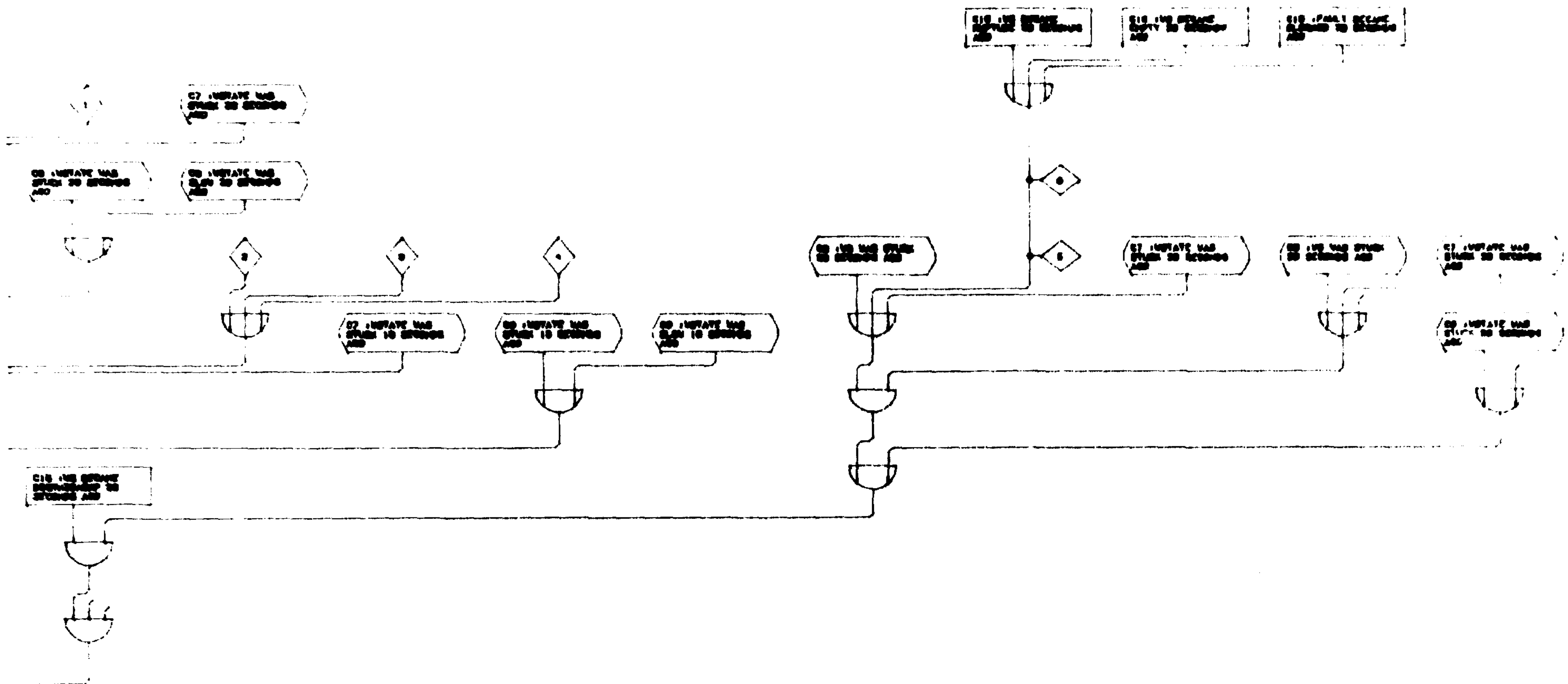
114) Fault in C4 :IN DID NOT BECOME SHUTOFF 10 SECONDS AGO
and in C5 :FAULT BECAME DISTHISUPP 20 SECONDS AGO
and in C13 :USTATE WAS SLOW 10 SECONDS AGO
and in C6 :USTATE WAS SLOW 10 SECONDS AGO

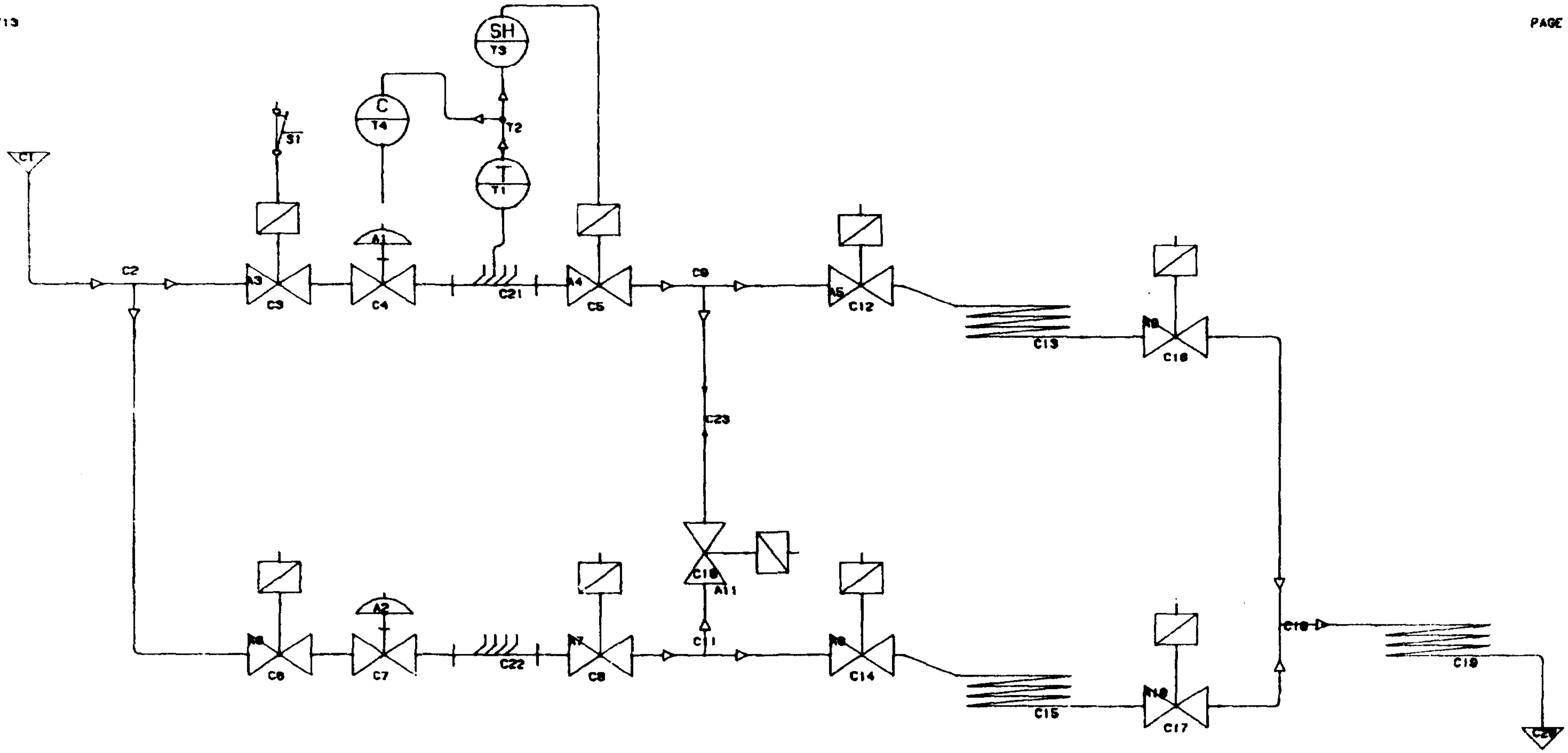






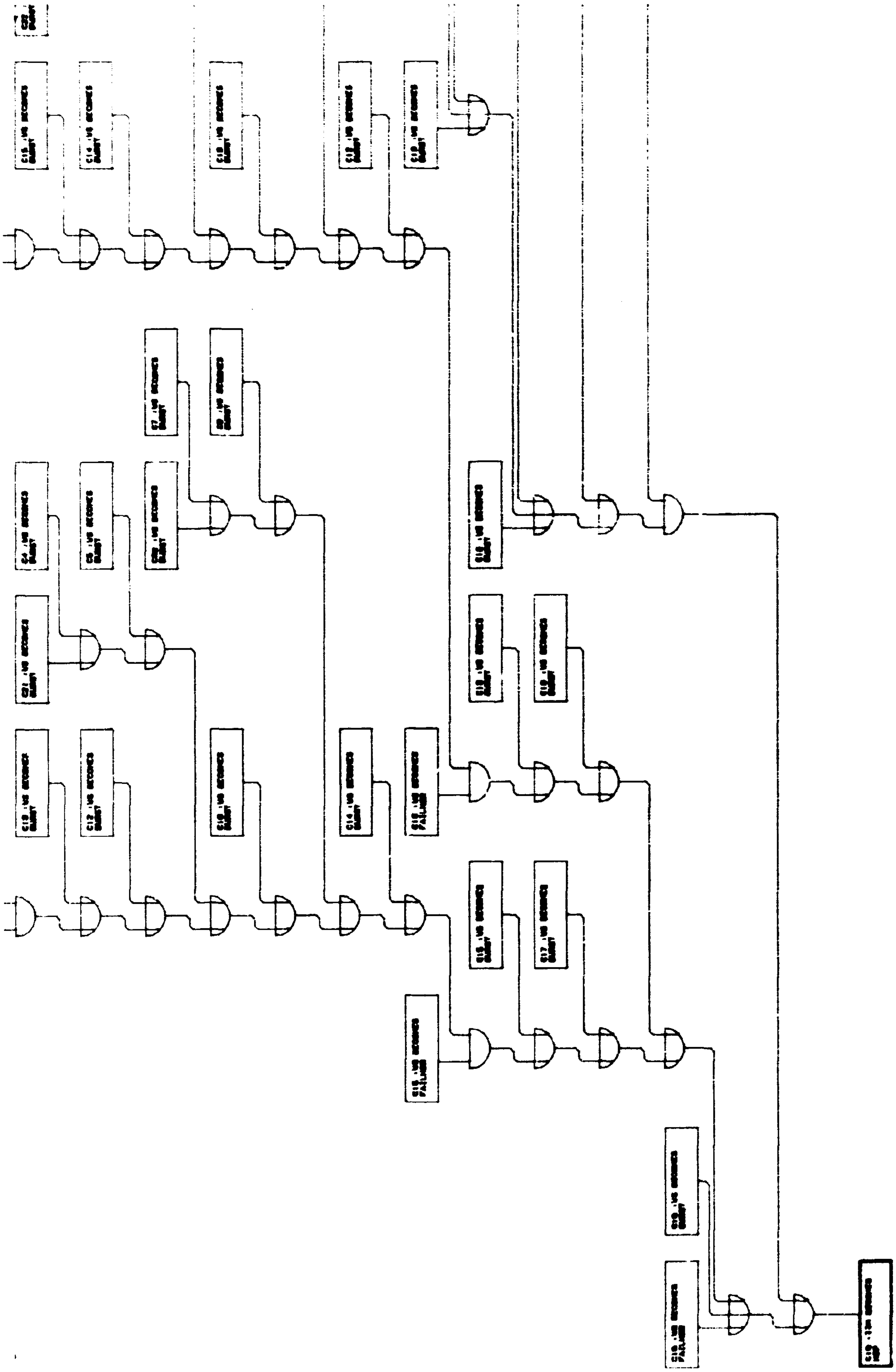






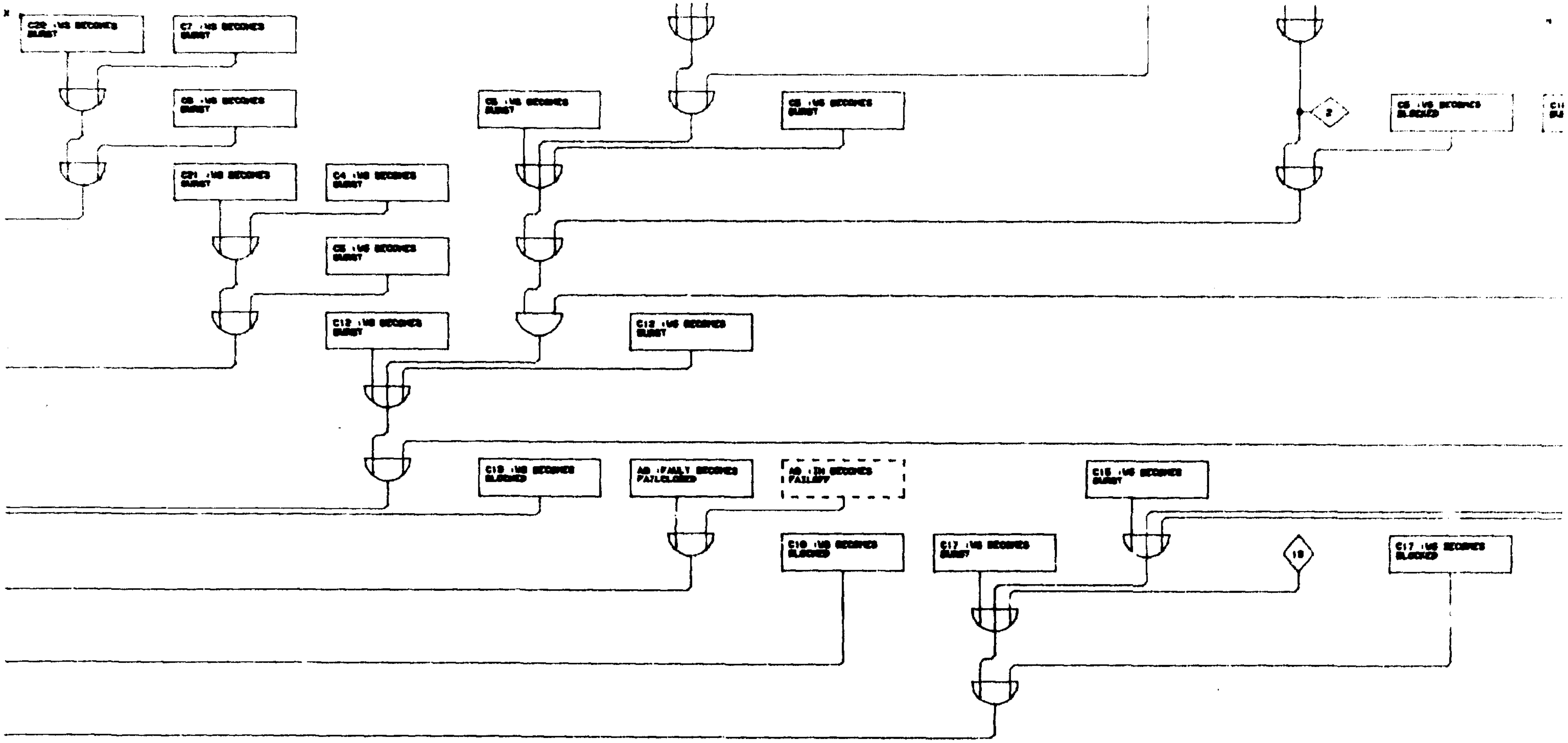
GAS REGULATOR NETWORK

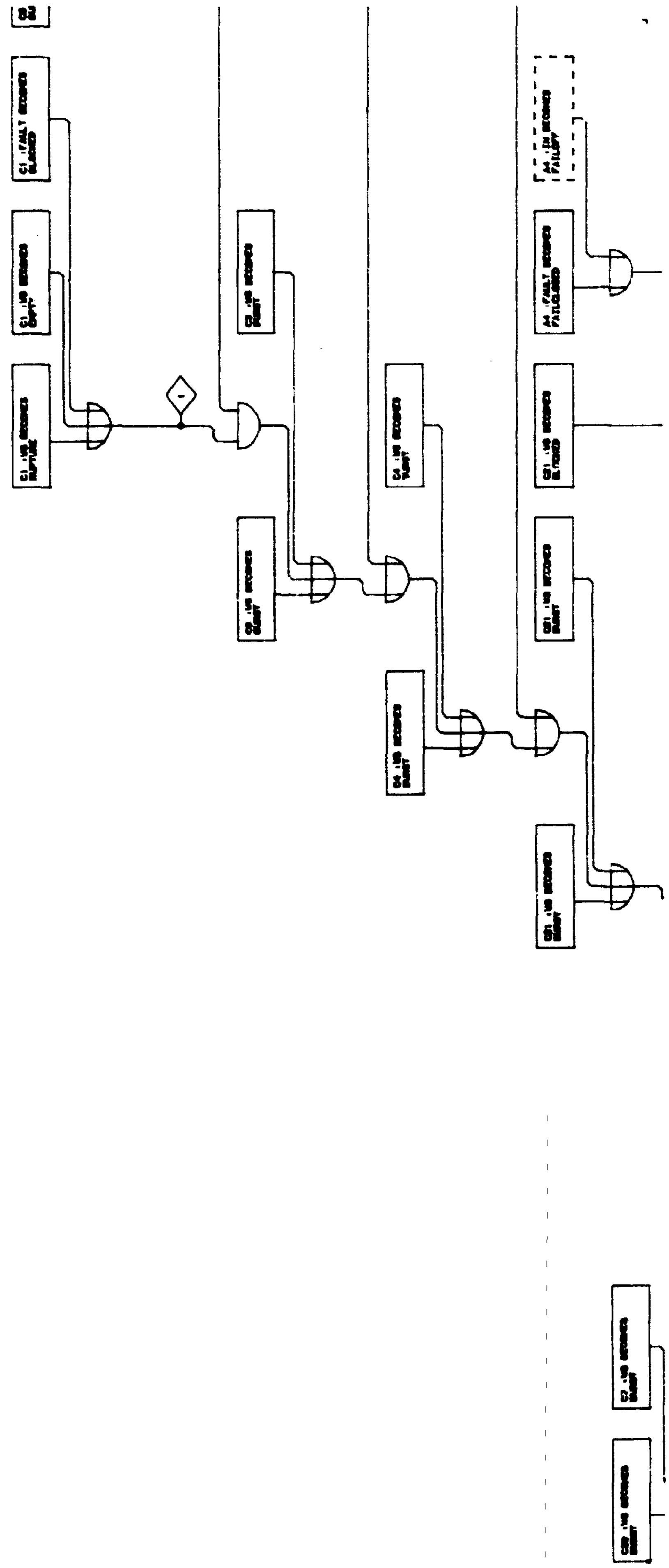
Test 28 (1,1)



Tables (1,2)

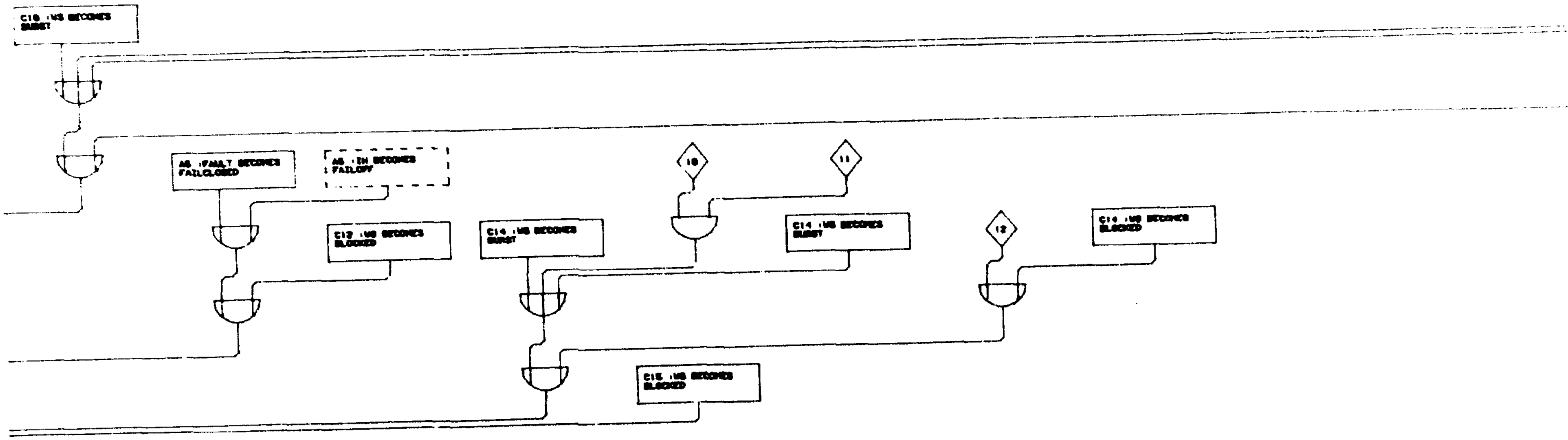
(2,1) TEST 13



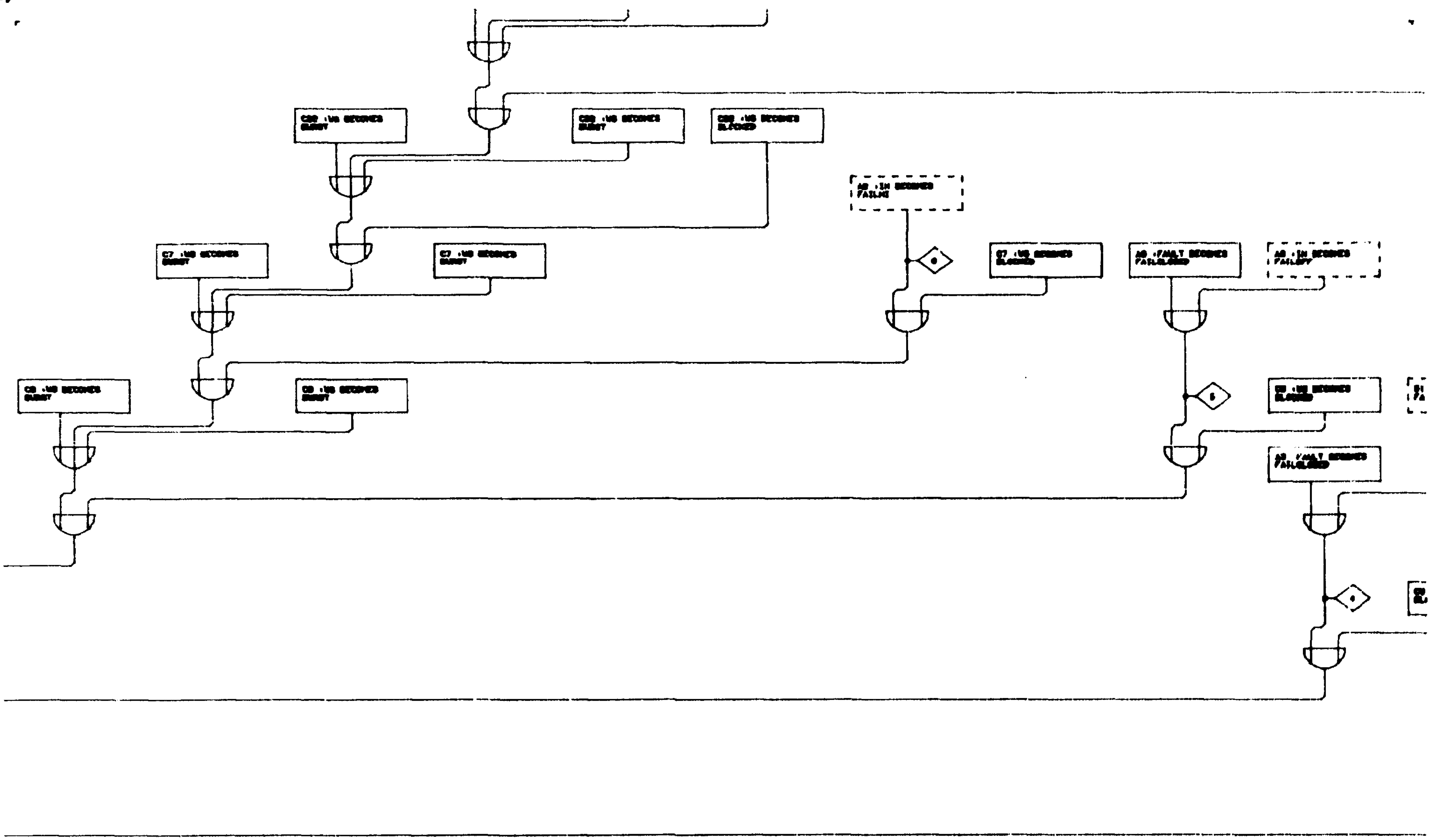


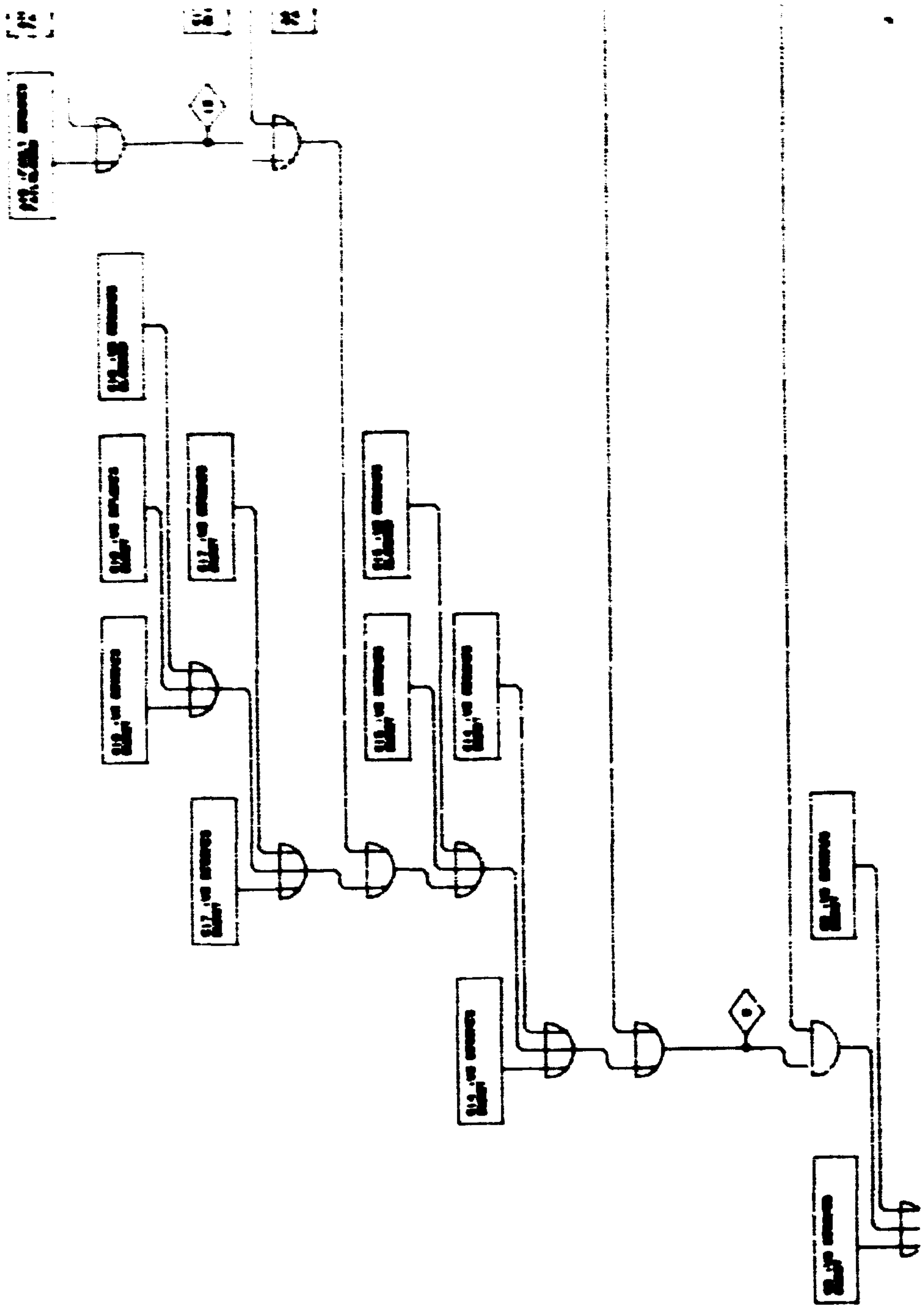
(2,2)

(3.1)

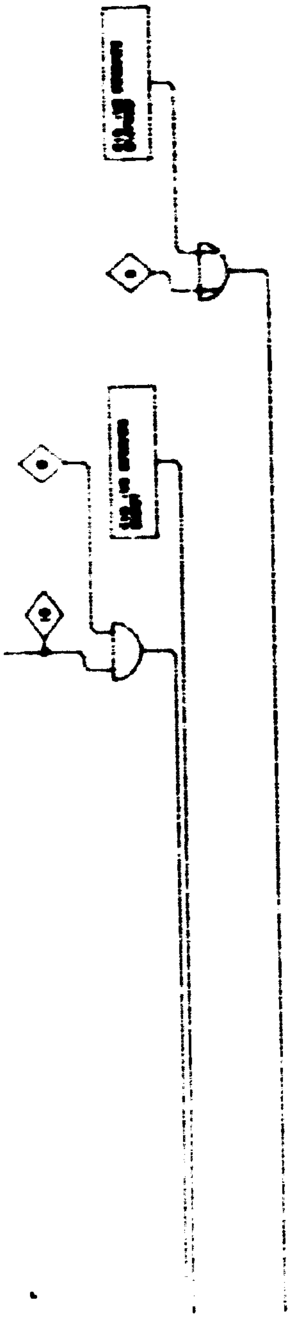

C10 :WS BECOMES BURST
A6 :FAULT BECOMES FAILCLOSED
A6 :IN BECOMES FAILOFF
C12 :WS BECOMES BLOCKED
C14 :WS BECOMES BURST
10
11
C14 :WS BECOMES BURST
12
C14 :WS BECOMES BLOCKED
C15 :WS BECOMES BLOCKED

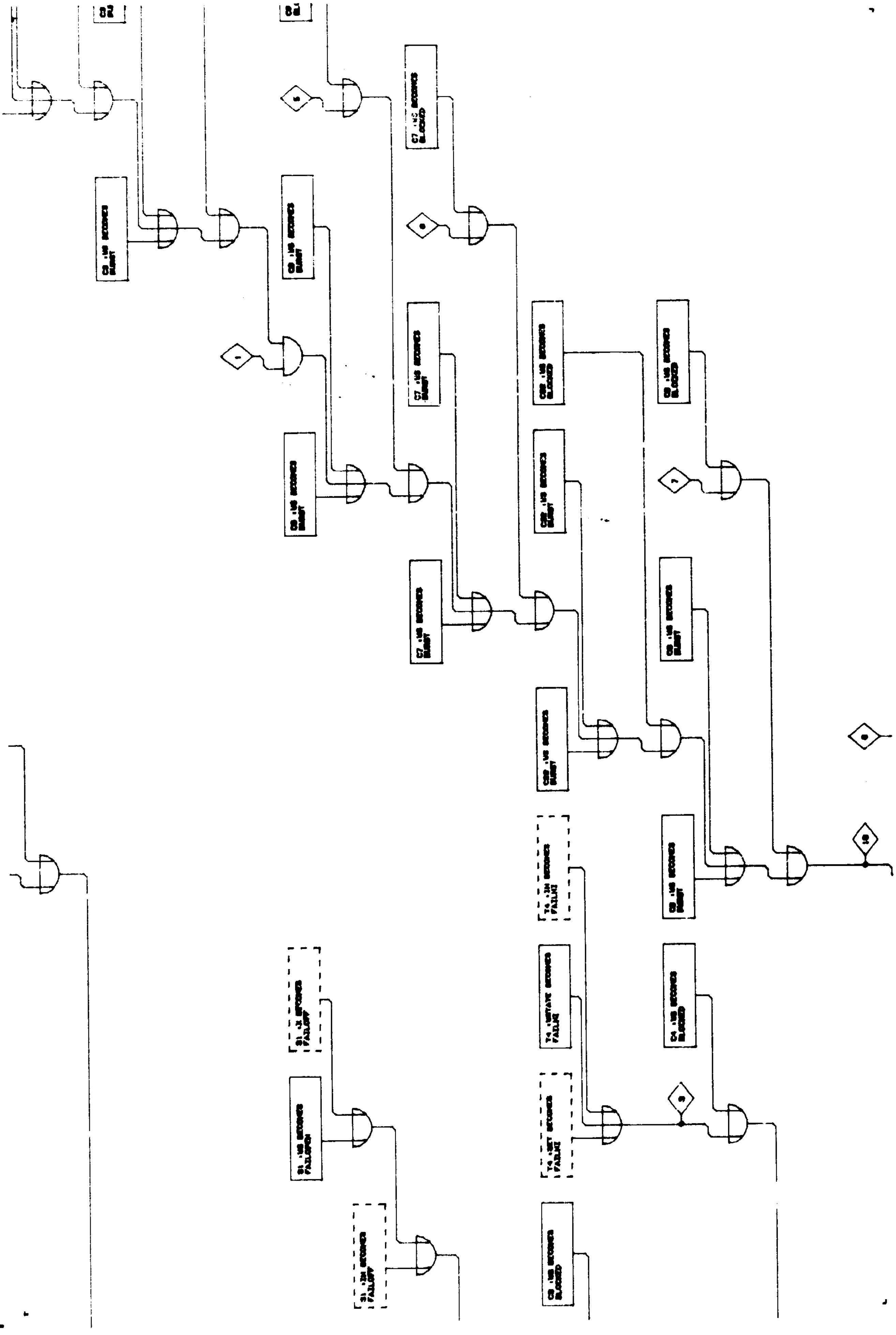
(3,2)



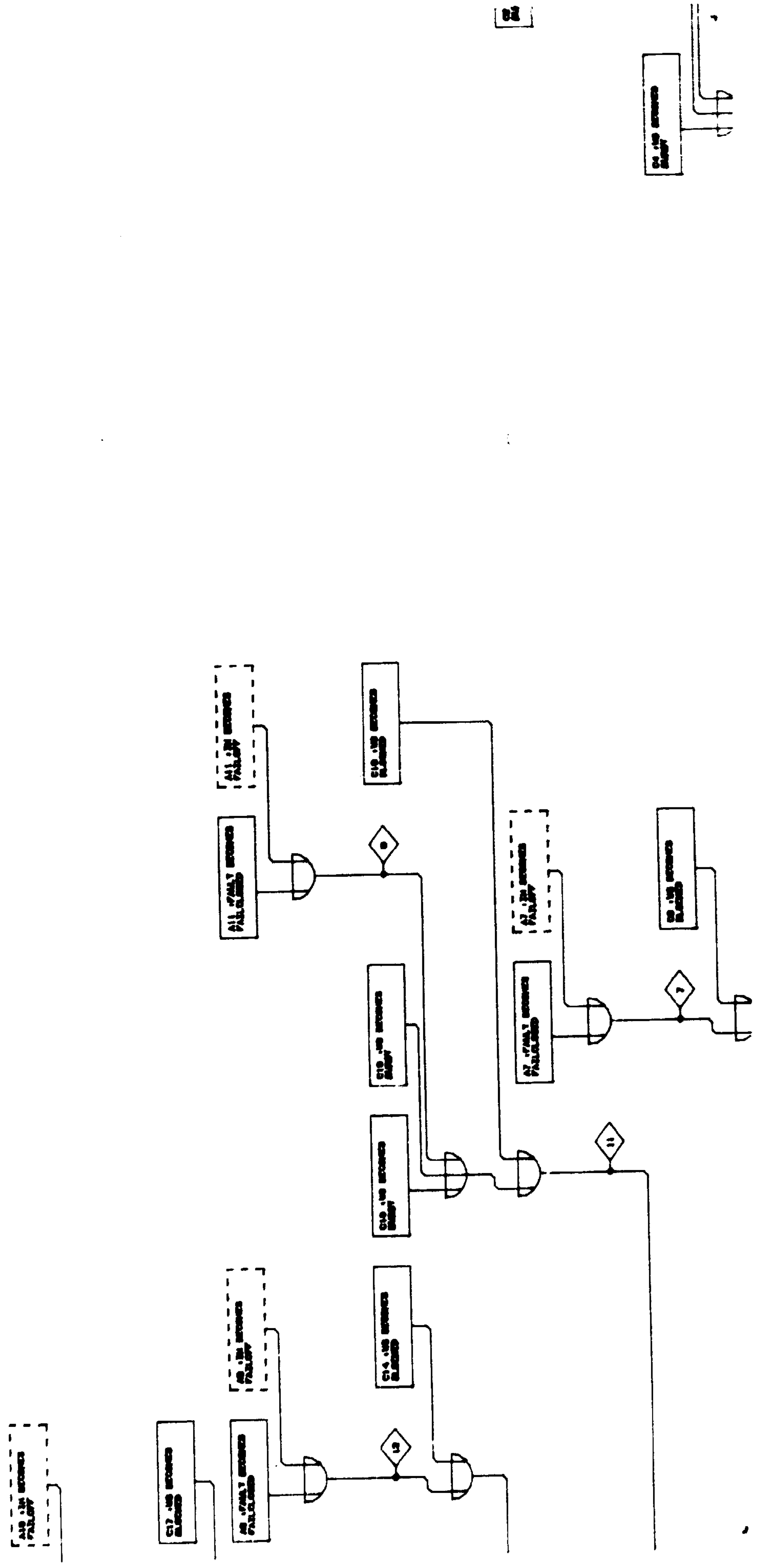


(3.3)



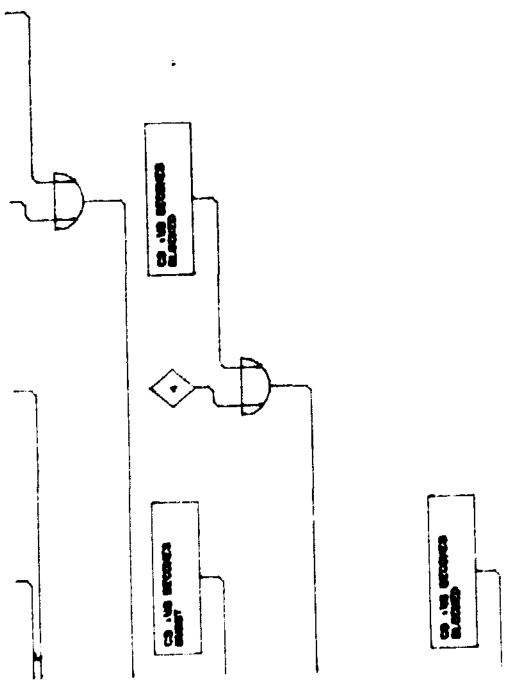


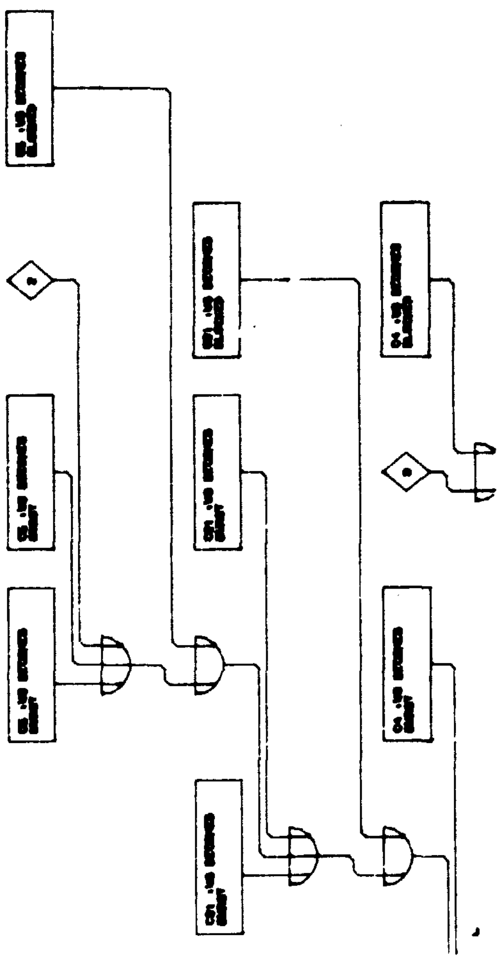
(4,2)



(4,3)

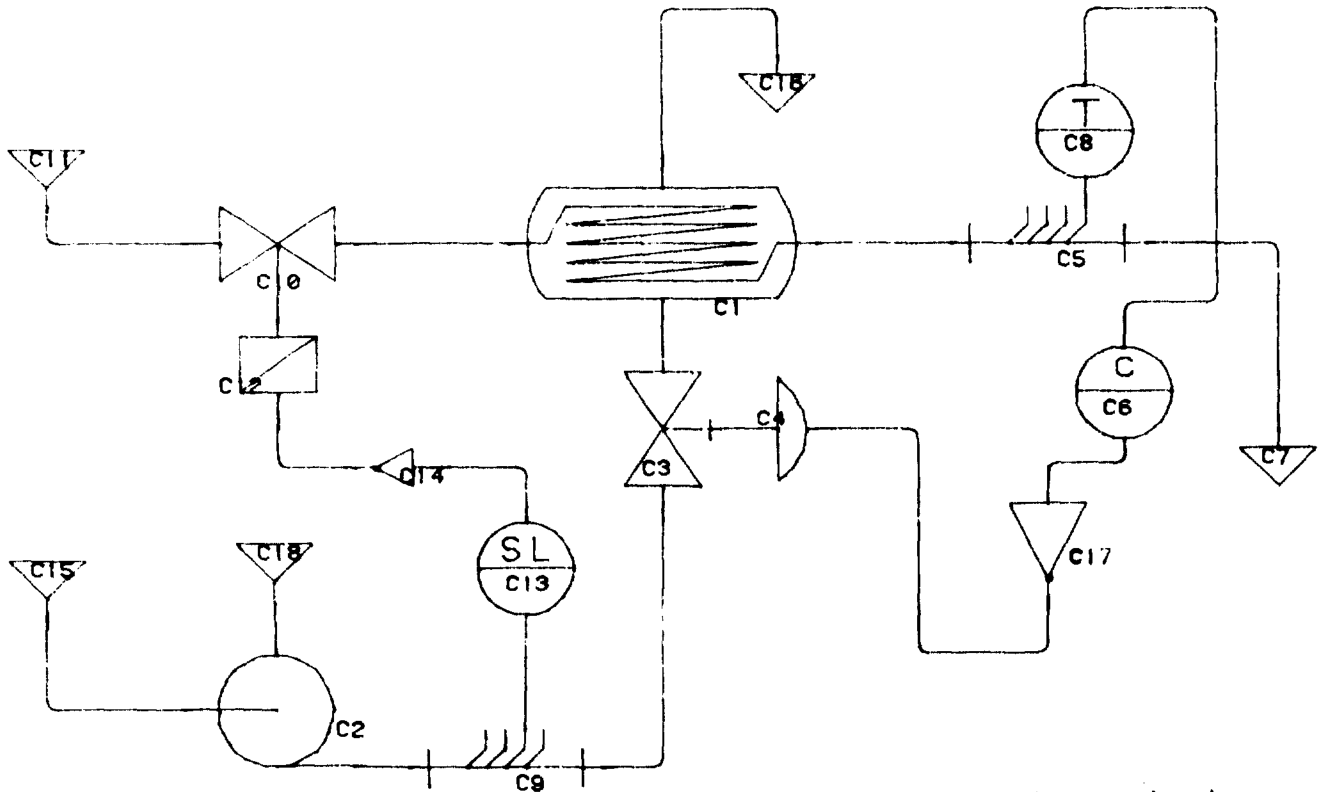
(5, 2)



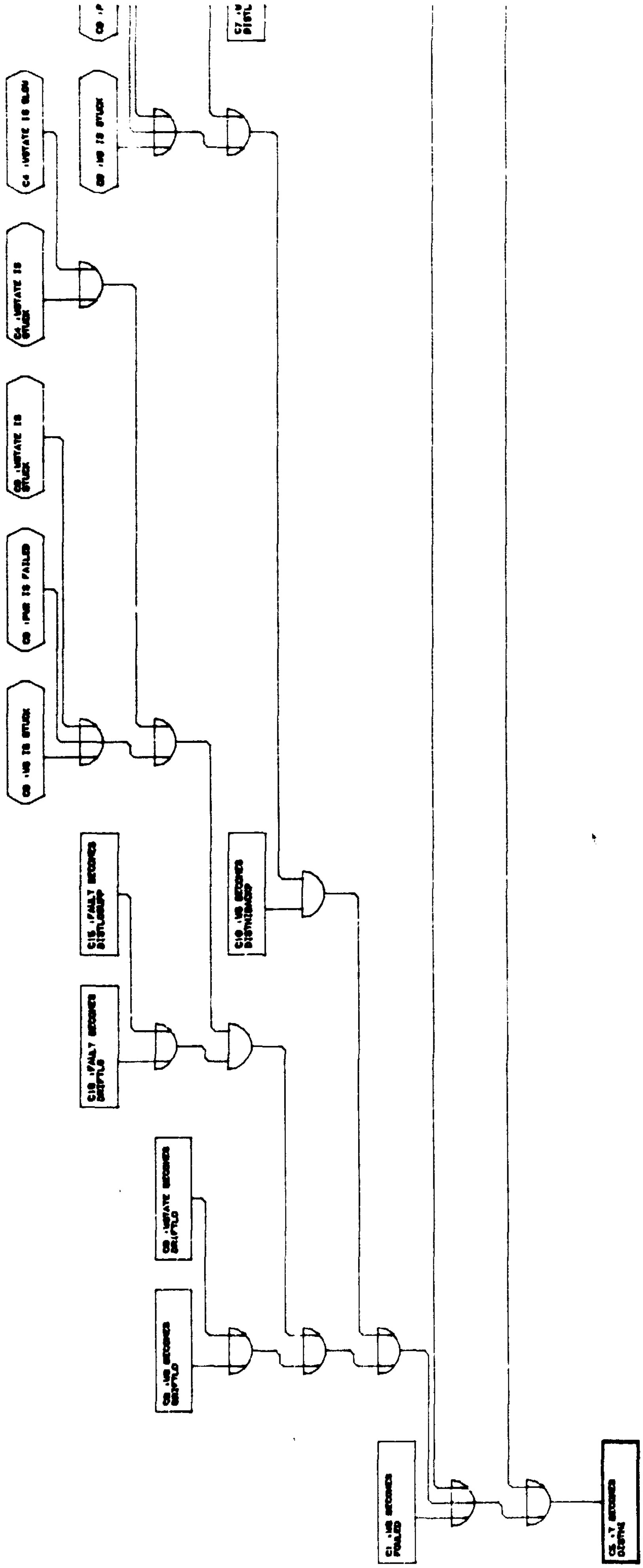


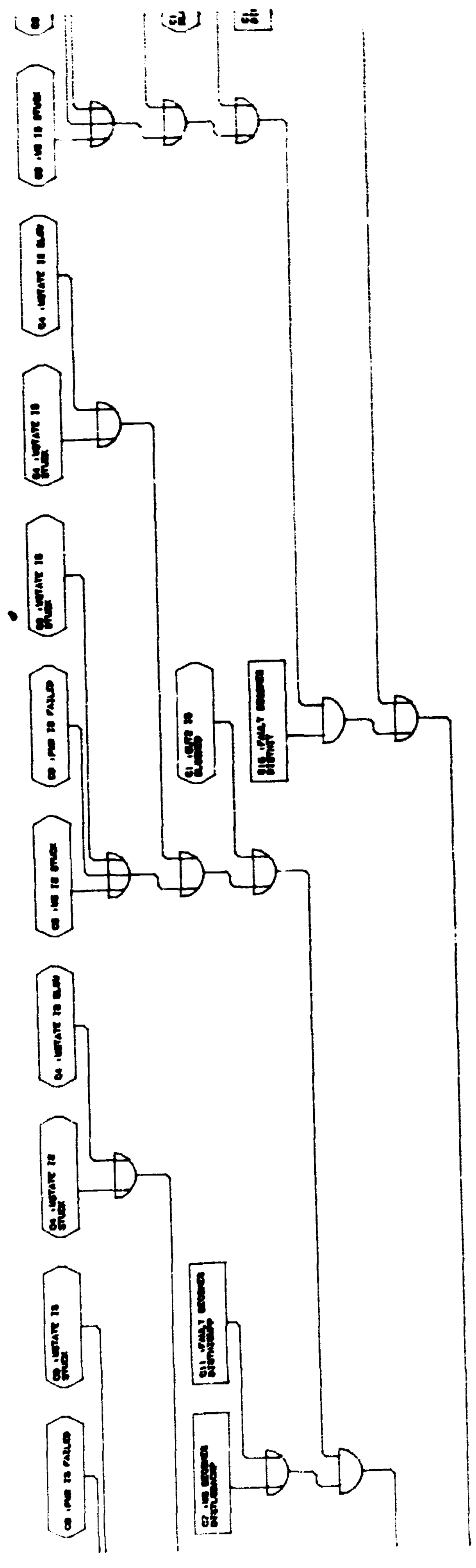
(5,3)

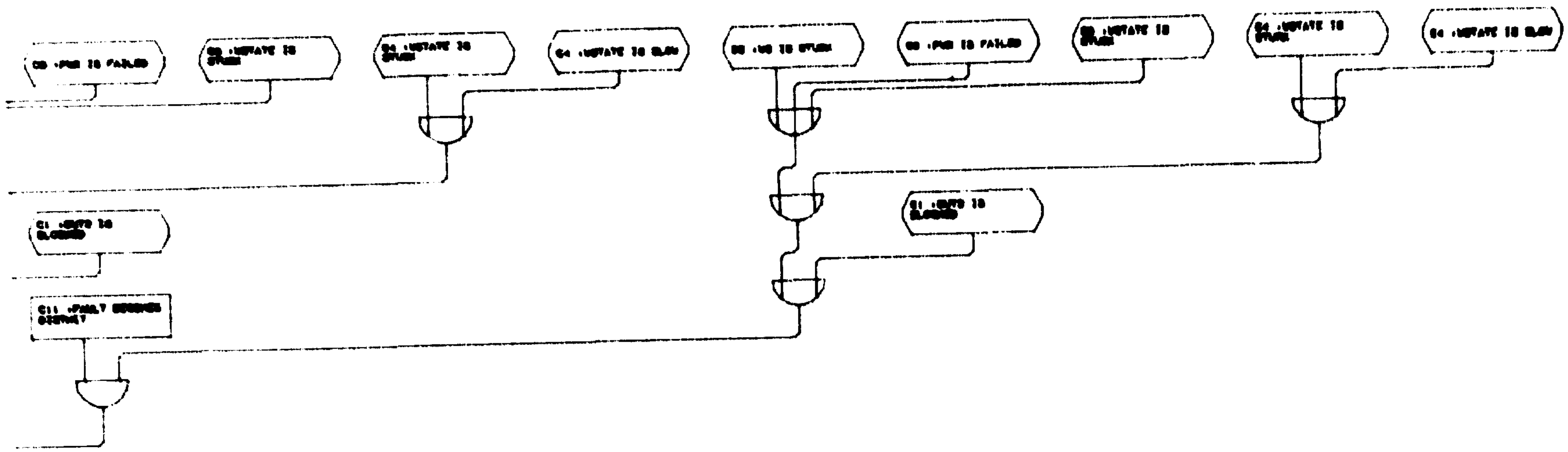
LAPP AND POWER'S HEAT EXCHANGER EXAMPLE



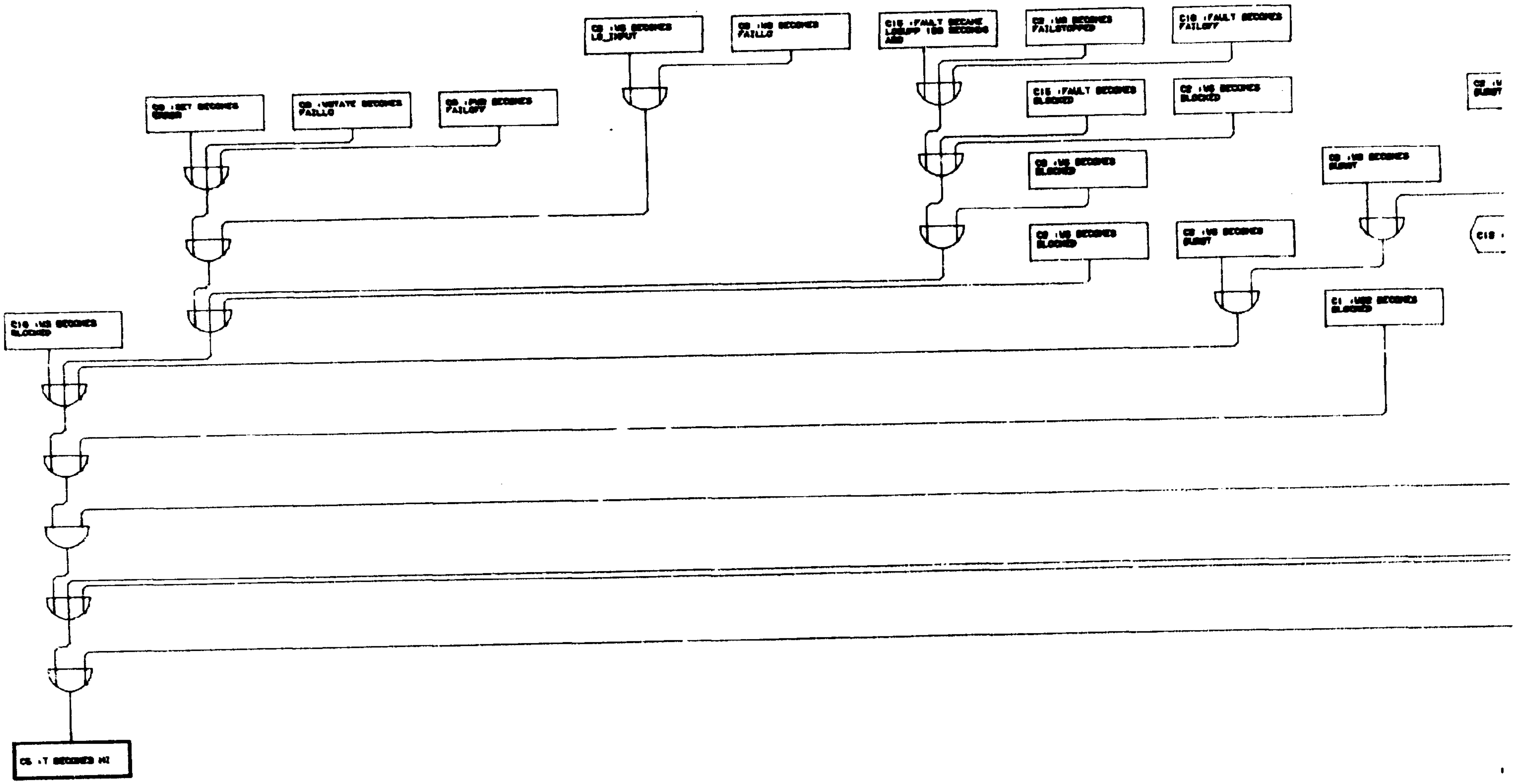
Model construction time
with RIKKE III on
PDP 11/34 : 3 min 14 sec.

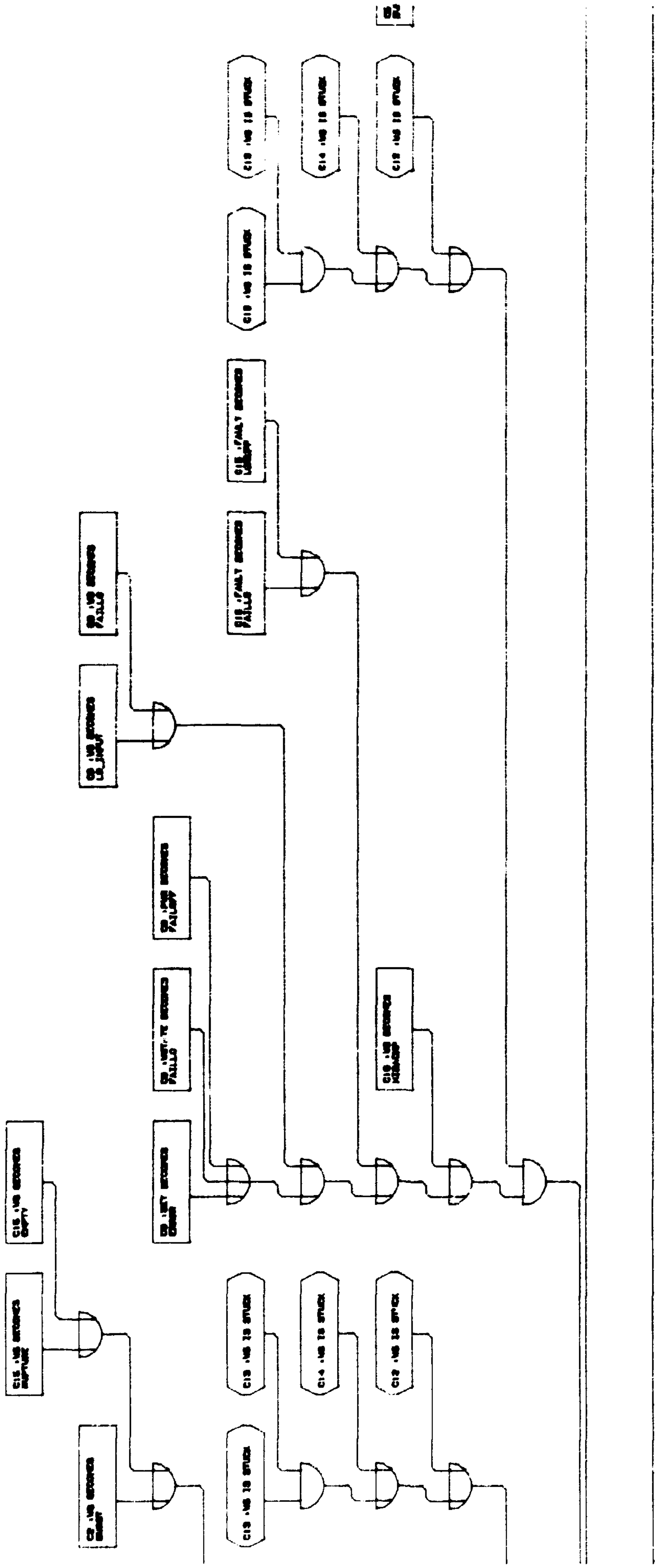


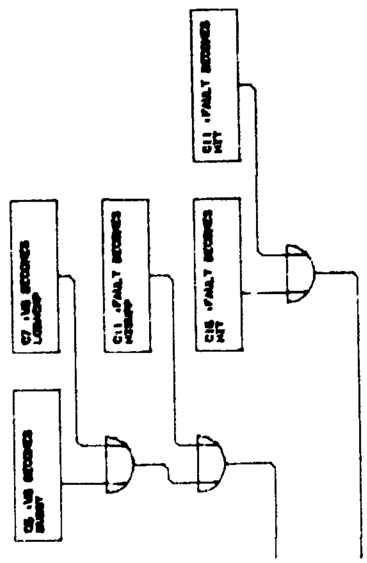


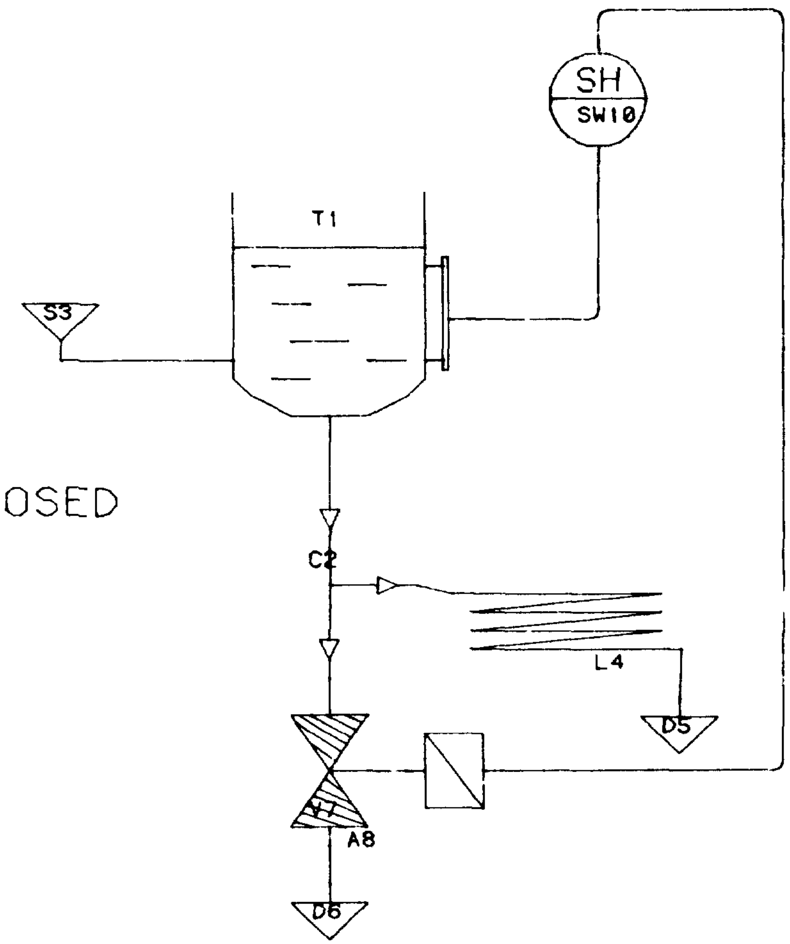


Fully automatic
construction : 7 min 16 sec
RIKKE III , PDP11/34

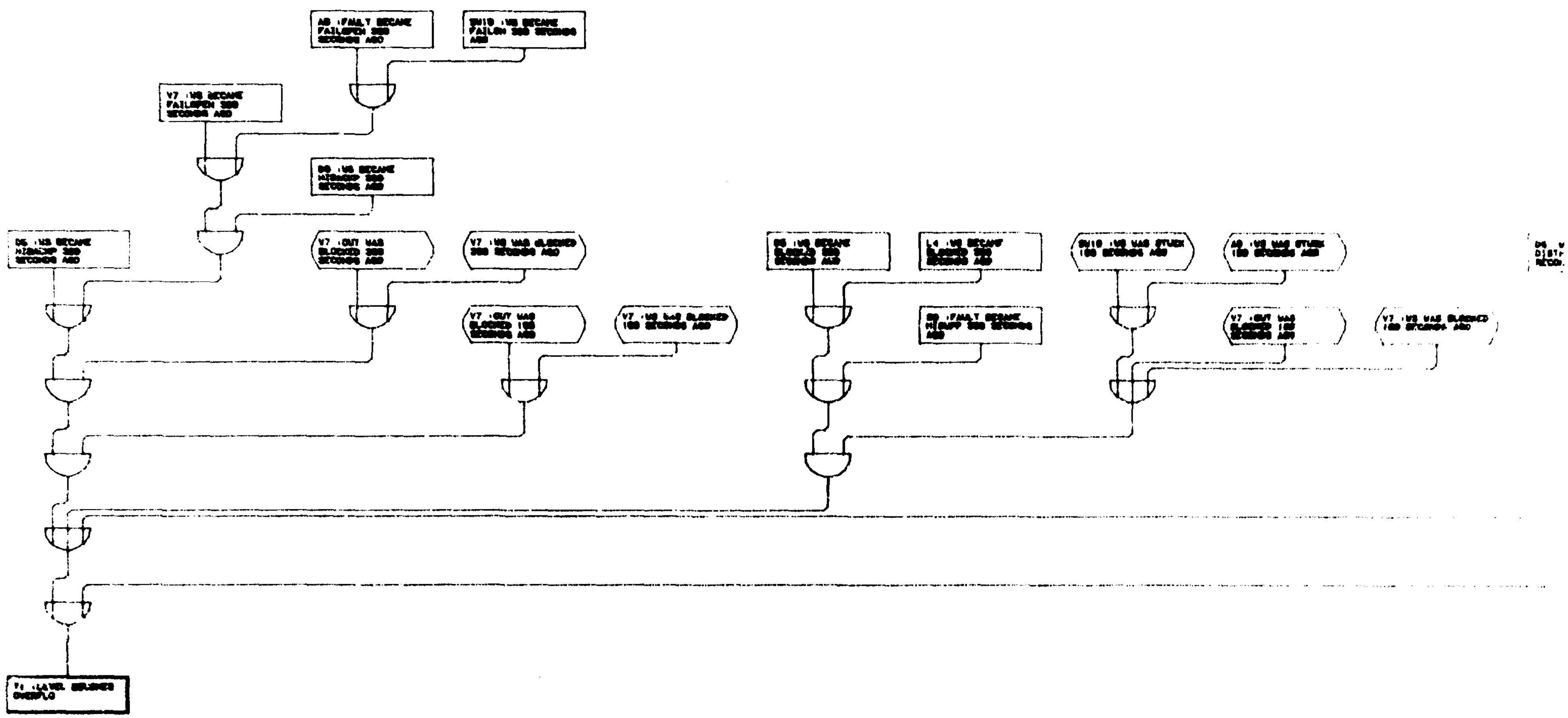




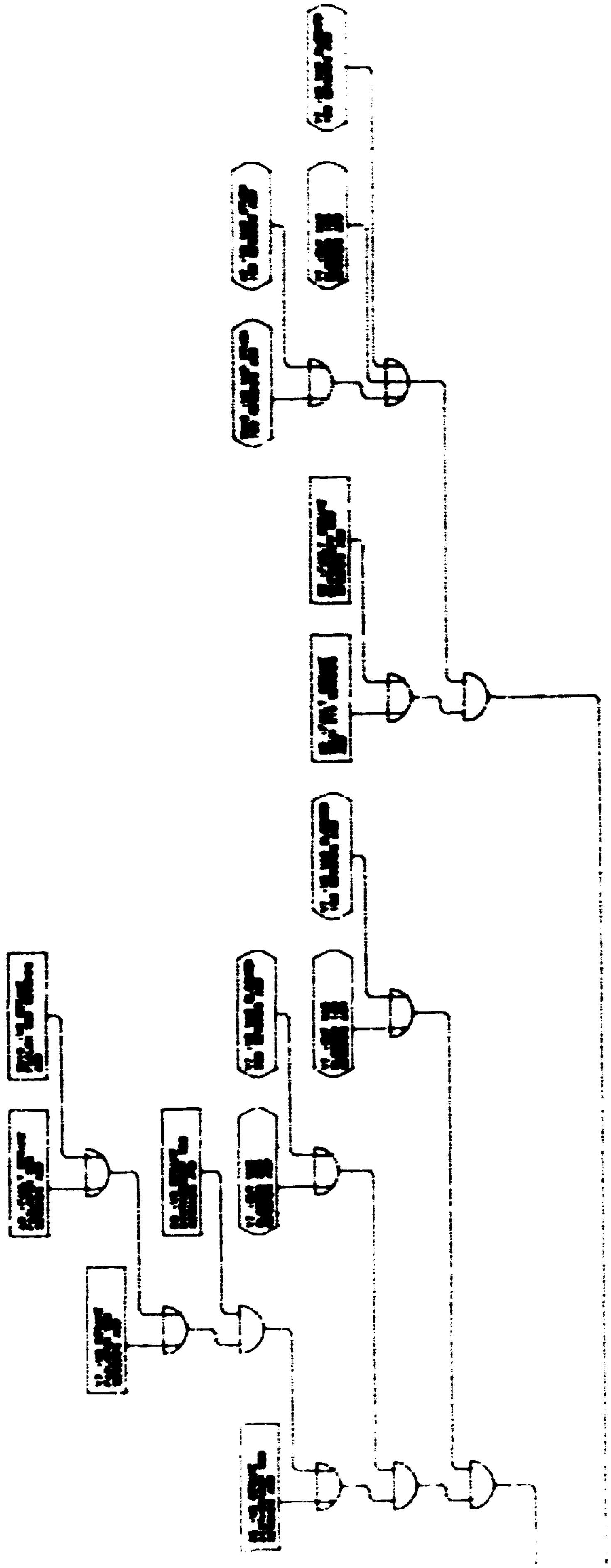




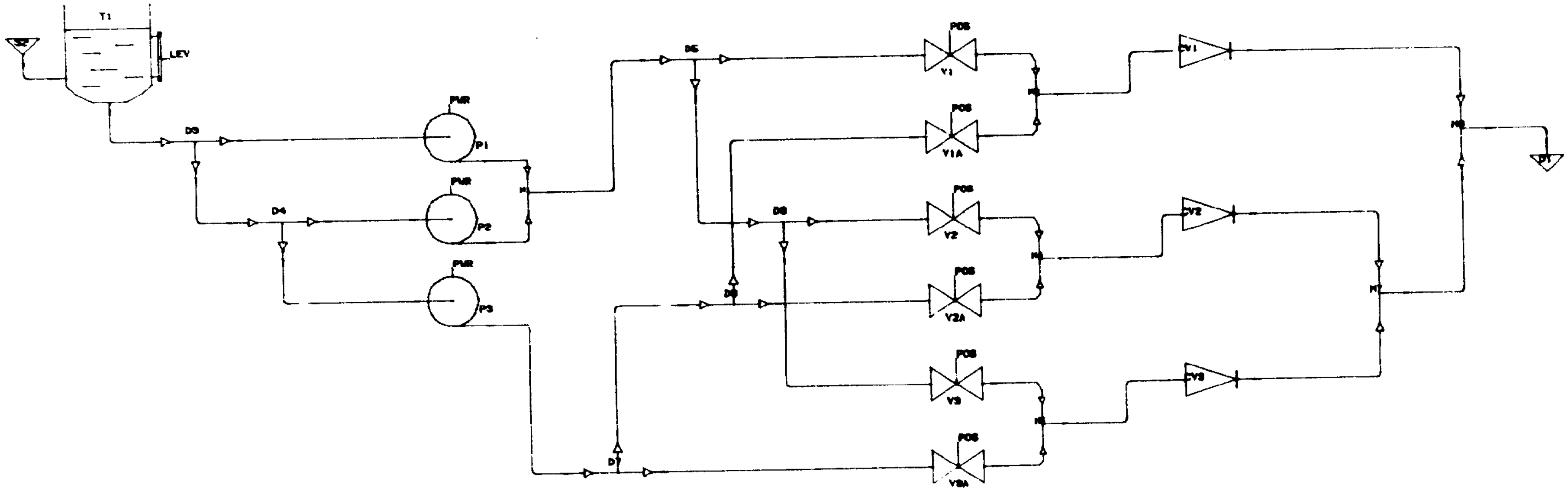
TEST OF CLOSED
VALVE
MODEL



AB :FAULT BECAME FAILOPEN 300 SECONDS AGO
V7 :VS BECAME FAILOPEN 300 SECONDS AGO
V7 :OUT WAS BLOCKED 300 SECONDS AGO
V7 :VS WAS BLOCKED 300 SECONDS AGO
V7 :OUT WAS BLOCKED 100 SECONDS AGO
V7 :VS WAS BLOCKED 100 SECONDS AGO
L4 :VS BECAME BLOCKED 300 SECONDS AGO
AB :VS WAS STUCK 100 SECONDS AGO
V7 :VS WAS BLOCKED 100 SECONDS AGO

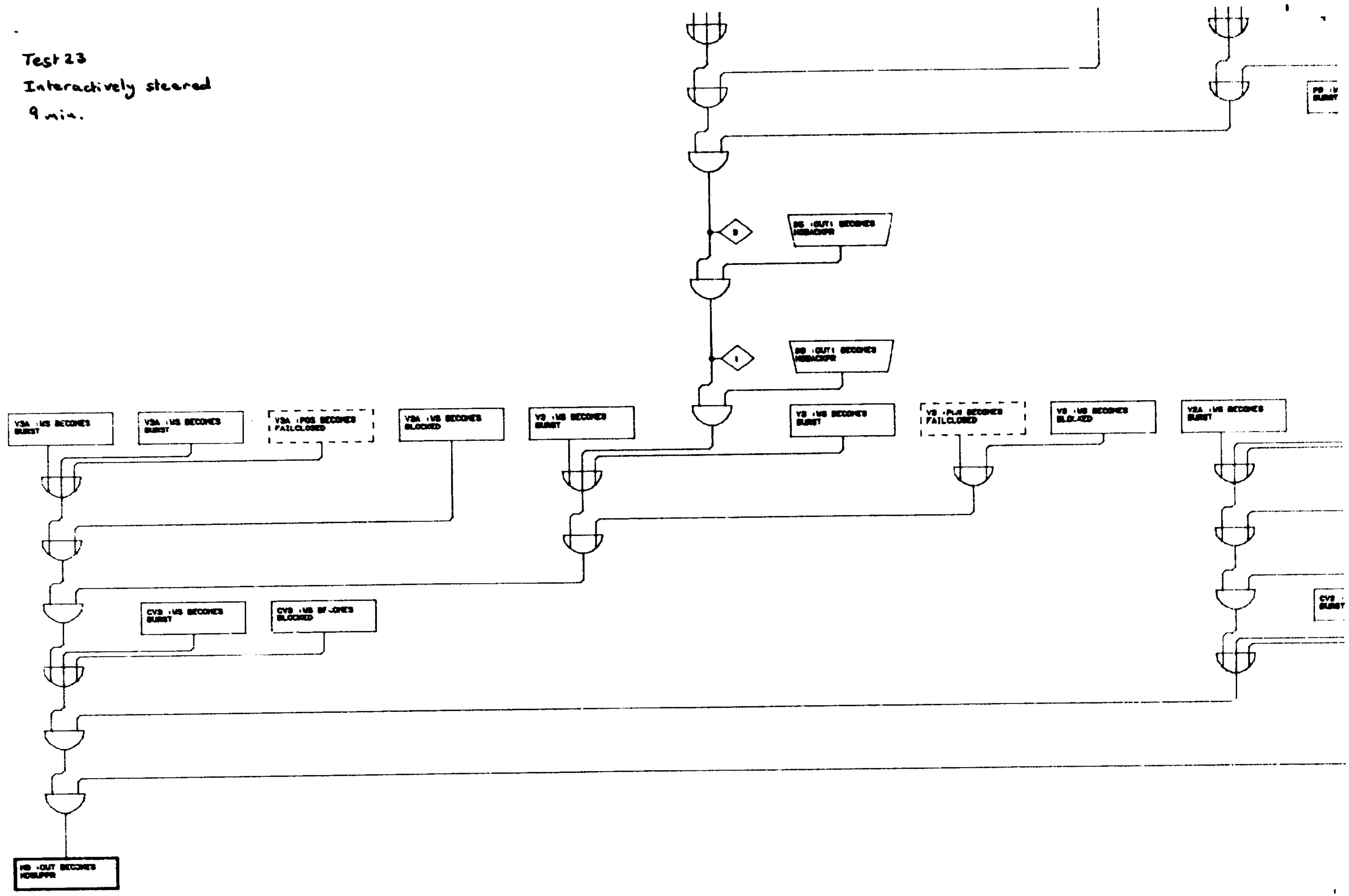


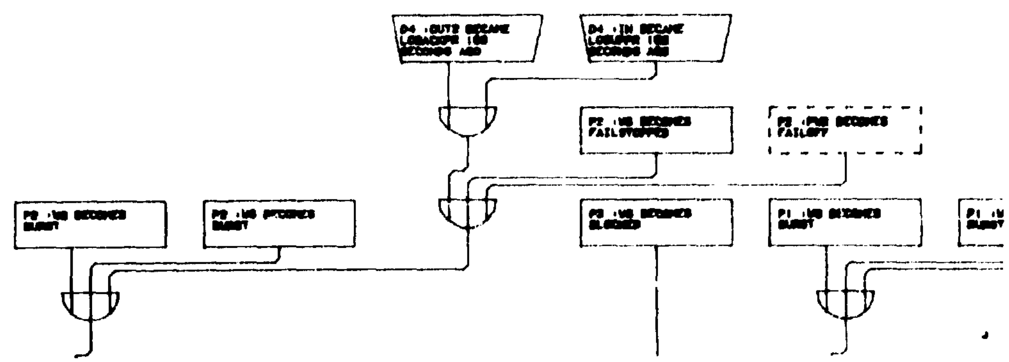
TEST23

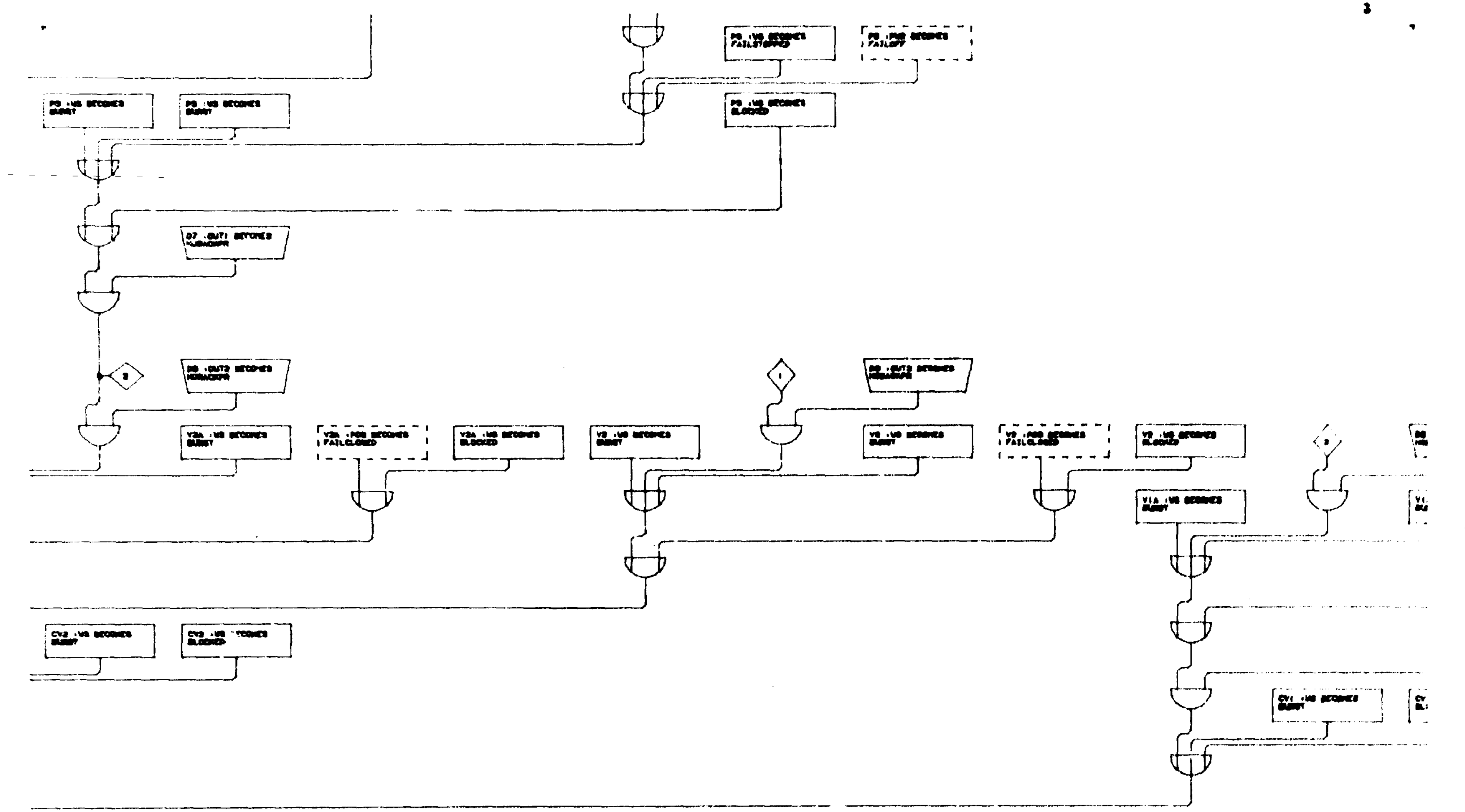


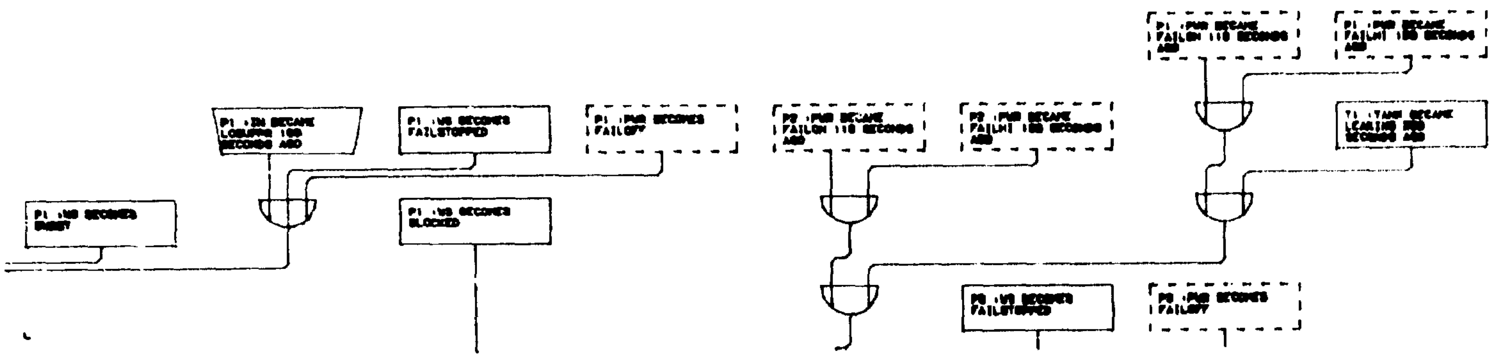
BENCHMARK EXERCISE SYSTEM 1:
FRAMMATOME AUX. FEEDWATER SYSTEM

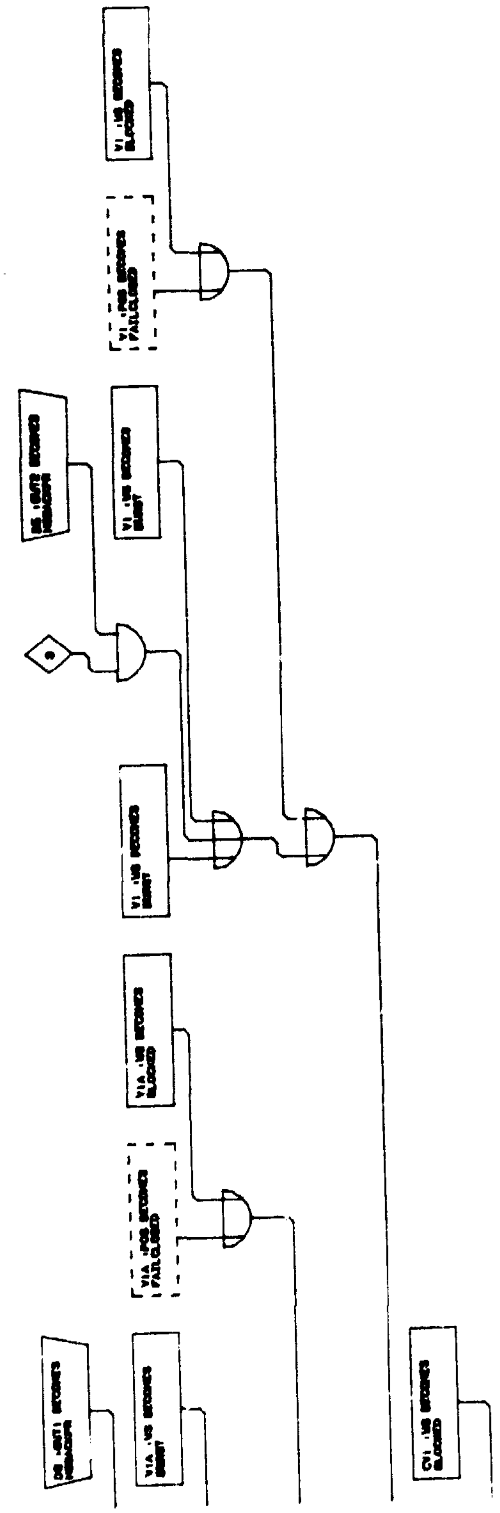
Test 23
Interactively steered
9 min.

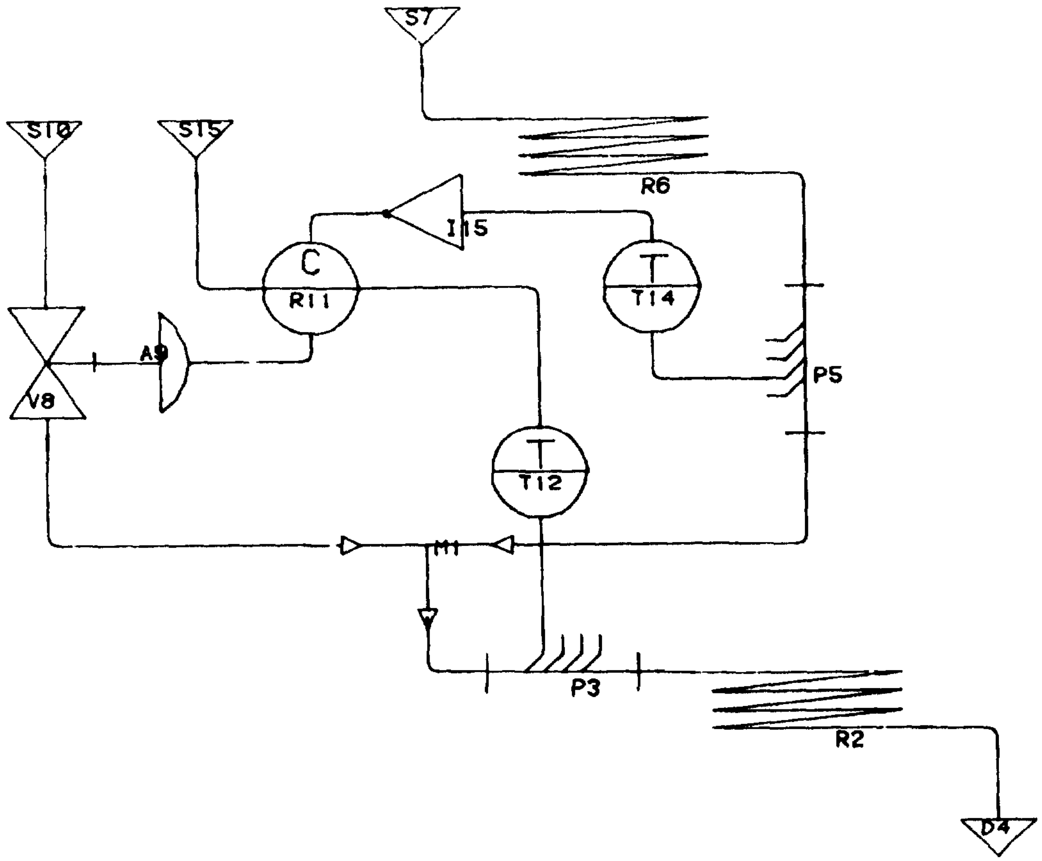



D4 :OUT2 BECAME
D4 :IN BECAME
FAILOFF


P8 :VS BECOMES
FAILSTOPPED
P8 :PVS BECOMES
FAILOFF
P8 :VS BECOMES
BURST
P8 :VS BECOMES
BURST
P8 :VS BECOMES
BLOCKED
D7 :OUT1 BECOMES
NOBACKPR
D8 :OUT2 BECOMES
NOBACKPR
2
1
D8 :OUT2 BECOMES
NOBACKPR
V2A :VS BECOMES
BURST
V2A :PVS BECOMES
FAILCLOSED
V2A :VS BECOMES
BLOCKED
V2 :VS BECOMES
BURST
V2 :VS BECOMES
BURST
V2 :PVS BECOMES
FAILCLOSED
V2 :VS BECOMES
BLOCKED
V1A :VS BECOMES
BURST
CV2 :VS BECOMES
BURST
CV2 :VS BECOMES
BLOCKED
CV1 :VS BECOMES
BURST
3



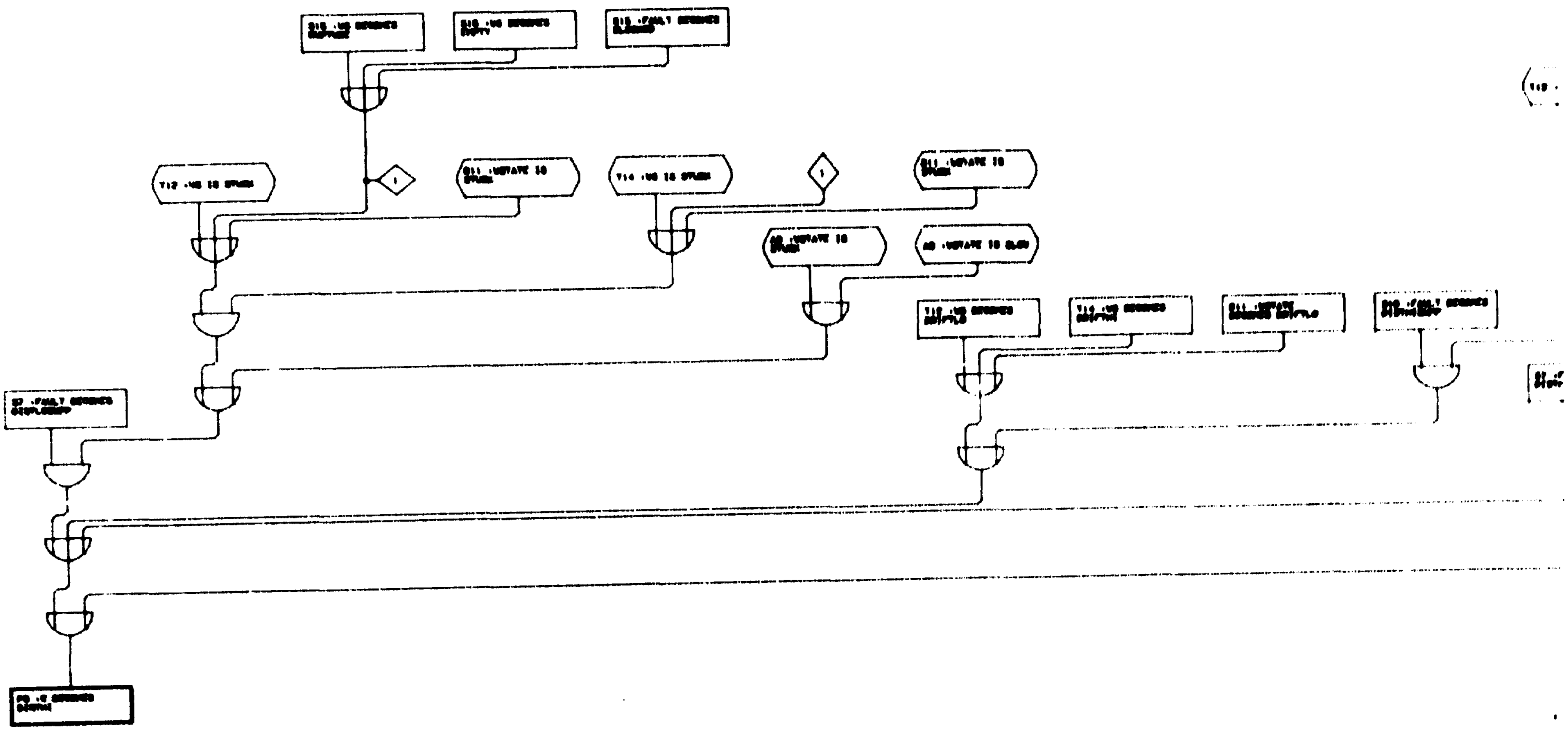

V1A :POS BECOMES
FAILCLOSED
V1 :POS BECOMES
FAILCLOSED

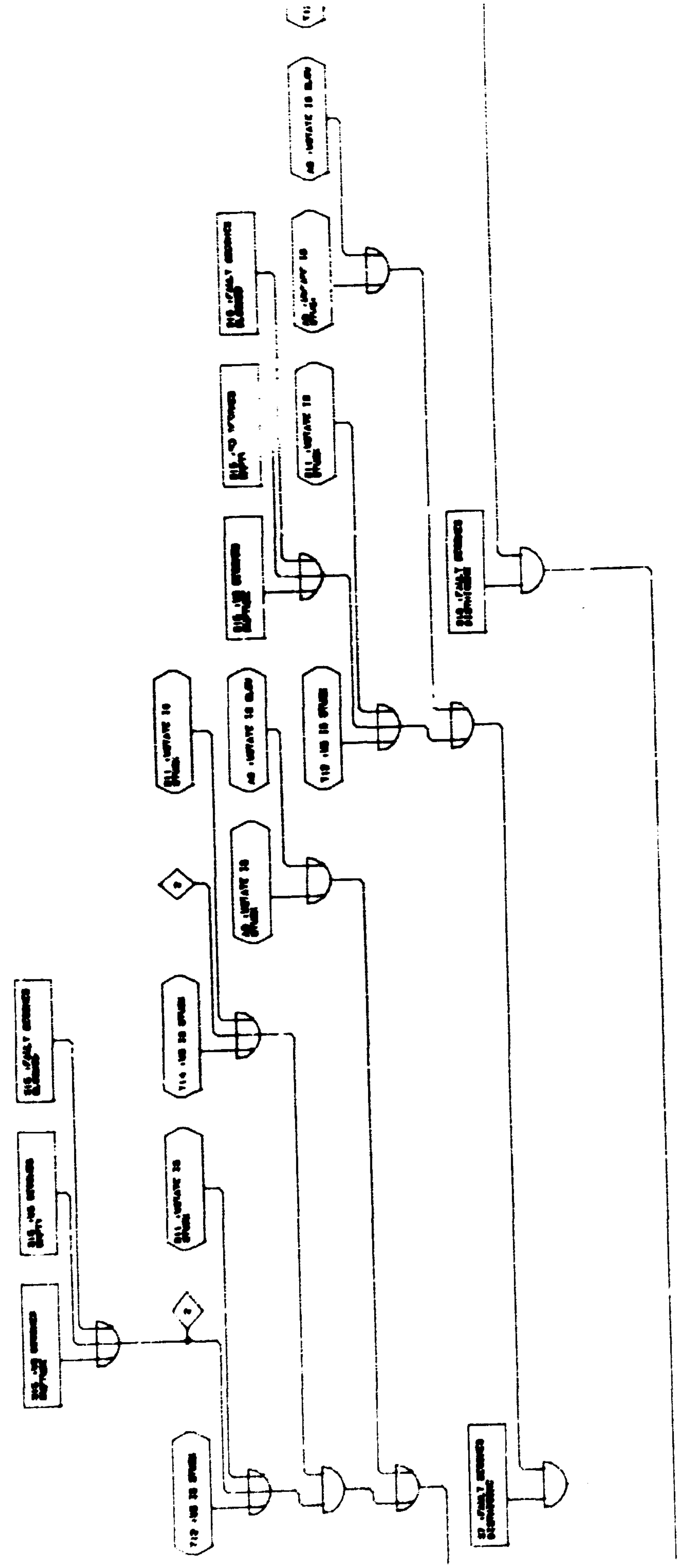


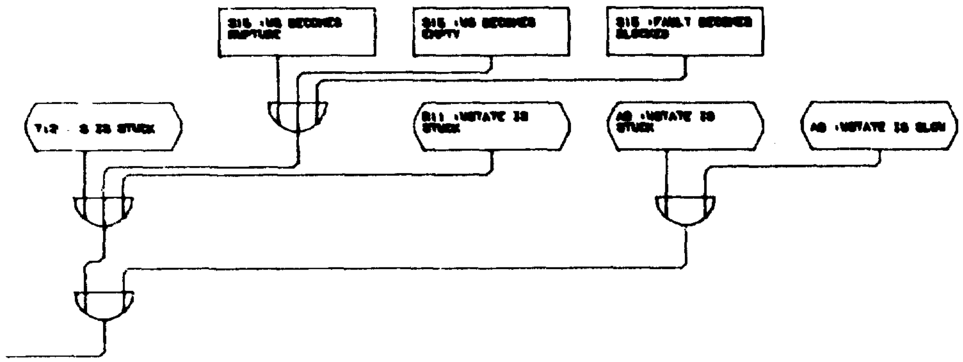
RATIO CONTROLLER FOR CONCENTRATION
REGULATION

Test 24

5 min 25sec






S15 :VS BECOMES RUPTURE
S15 :VS BECOMES EMPTY
S15 :FAULT BECOMES BLOCKED
T:2 - S IS STUCK
S11 :VSTATE IS STUCK
A8 :VSTATE IS STUCK
A8 :VSTATE IS SLOW

APPENDIX

Coding of event and condition descriptions.

The principles for coding of event descriptions in the FTLIB component model library were described in volume 1. Here a short reference list of codes is provided.

Events are described in the form

<variable> → <value>

Values for events are either simple, e.g., ON, BLOCKED, etc., or composed of a stem, describing the size and direction of the event, together with prefixes and suffixes, expressing the cause, direction, and target for the event.

Variables

The most usual variables for components are

IN	input
OUT	output
WS	working state
POS	position
FAULT	fault state
IIN	an internal variable corresponding to IN, used for TOP events. Generally, only internal variables, not on port lists, should be used for TOP events, since only a one way search for causes of external events is made.
IOUT	an internal variable corresponding to OUT

P	pressure
F	flow
T	temperature
C	concentration
LEVEL	level
LEV	external variable corresponding to LEVEL

Values

For disturbances, the description stems are as follows:

VHI	very high, so high that shutdown cannot prevent damage
HI	high, so that only shutdown can prevent damage
DISTHI	high, but control actions can prevent damage
DISTLO	low, but control actions can prevent damage
LO	low, but shutdown can prevent damage
ZERO, NO	absolute zero level disturbances
REV	reverse
NEG	negative

For control loop signals, disturbances

DRIFT -	slow change in signal, e.g. DRIFTHI
FAILON	
FAILOFF	

Additionally, for zero values of pressure and flow there are values

NOP	no pressure
NOF	no flow
BLOCKED	flow is prevented by blockage or valve closure
ATM	no pressure because of direct connection to atmosphere
EMPTY	zero level

To many of these stems, suffixes may be appended to identify the physical variable affected.

-CUR	current
-V	voltage
-P	pressure
-F, -FLO	flow
-CONC	concentration
-T	temperature
-VAC	vacuum

For example

HIP	high pressure
DISTHICONC	slightly high concentration
LOT	low temperature

For pressure and flow, suffixes are also provided to describe the source and target of a disturbance

-SUP-	disturbance in supply
-BACK-	disturbance downstream
-R	disturbance able to affect a resistive load

-C	disturbance able to affect a capacitative load only (used with pressure disturbance)
-T	disturbance able to affect piping past a tee junction (used with flow disturbances)

Examples

HISUPPR	High supply pressure able to affect a resistive load
DISTLOBACKPC	slightly low downstream pressure able to affect a capacitative load
NOSUPFLOTR	no supply flow, feeding a T junction with a resistive load

Note. HIBACKP may be caused either by a rise in downstream resistance or by a disturbance in a downstream flow source. At a later date it may be worthwhile to distinguish these, by introducing HIREVP, since the second class of causes can cause reverse flow, while the first cant.

Simple disturbances are provided to cover contamination etc.

GAS	flow becomes gas only
LIQUID	flow becomes liquid only
DIRTY	flow becomes dirty
GRITTY	flow becomes gritty
CONTAMINATED	flow becomes contaminated
SCUM	flow becomes SCUM, can cause overflow
AIR	air sucked in
SUBST1PRESENT	used to describe disturbances
SUBST1HI	causing unwanted reactions
SUBST1LO	substance 1 present, high, low, etc. Also for substance 2

Compensating or control actions

These are

COMP-	regulator compensation of a variable, e.g., COMPHISUPP - compensating pressure supply
DELTA-	regulator actions acting on differential signals, used with level control, etc.
CONTHI-	control signal high
CONTLO-	control signal low
ON	control signal on
OFF	control signal off
SHUTOFF	flow path closed to prevent disturbance
RELIEVED	opened to atmosphere to prevent overpressure
DRAINED	opened to a drain or dump tank, to prevent overflow
CLOSED	valve closed, circuit closed
OPEN	valve open, circuit open

Structural conditions

These are used to describe the character of interconnections in the system diagram.

SUP	connected to a supply
R	is resistive, resistive load on source
C	is capacitative, tank load or source

Failure modes

A complete list of failure modes is impossible to give, but an initial list is

BLOCKED	blocked by deposits, crud, debris, crushing, etc.
FAILOPEN	valve failed open or broken
FAILCLOSED	valve failed closed, stem broken, etc.
FAILON	signal failed on
FAILOFF	signal failed off
BURST	pipe, valve, pump etc., burst
FAILSTOPPED	failure causing stopping of pump or failure to start on demand
LEAK	leakage over a valve seat
EXLEAK	external leakage from flange, pump, etc.
STUCK	fails to operate on demand due to jamming, sticking, or functional failure

SHORTED	short circuited to earth
FAIL OPENCIRC	open circuit
STUCKCLOSED STUCKOPEN	failures of contacts
FAILNOR	fails no resistance
FOULED	fouling on heat transfer surface
EMPTY	zero level in supply
RUPTURED	as for burst

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Abstract

This second volume describes the construction of fault trees for systems with loops, including control and safety loops. It also gives a short summary of the event coding scheme used in the FTLIB component model library.

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